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AMERICAN GEOPHYSICAL UNION

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INTRODUCTION

The American Geophysical Union is the American National Committee of the International Geodetic and Geophysical Union, and the Executive Committee of the American Geophysical Union is the Committee on Geophysics of the National Research Council. The object of the Union is to promote the study of problems concerned with the figure and physics of the Earth, to initiate and coordinate researches which depend upon international and national cooperation, and to provide for their scientific discussion and publication. In the accomplishment of this object, the Union is divided into six sections in accordance with the organization of the International Geodetic and Geophysical Union as follows: (*a*) Geodesy, (*b*) Seismology, (*c*) Meteorology, (*d*) Terrestrial Magnetism and Electricity, (*e*) Oceanography, (*f*) Volcanology. The International Geodetic and Geophysical Union has also a Section of Scientific Hydrology, but thus far the American Geophysical Union has not formed such a section; matters pertaining to scientific hydrology referred to the American Geophysical Union are looked after by a special Committee on Scientific Hydrology of which G. W. Littlehales is Chairman for the year 1928-1929.

Annual assemblies of the Union and annual meetings of its sections for the discussion of reports and symposia are held each year. Thus far there have been nine such assemblies and meetings, all held in Washington, D. C. The transactions of these annual assemblies and meetings have been published as bulletins of the National Research Council as follows: Second, 1921, Bulletin No. 17; fourth, 1923, Bulletin No. 41; sixth, 1925, Bulletin No. 53; seventh, 1926, Bulletin No. 56; eighth, 1927, Bulletin No. 61; and ninth, 1929, the present volume. The transactions of the first, third, and fifth annual meetings in 1920, 1922, and 1924, respectively, were devoted to discussion, there being no scientific papers presented; therefore, these transactions were not printed but were mimeographed for limited distribution only.

The ninth annual assembly of the Union and the meetings of its sections were held April 26 and 27, 1928, in the building of the National Academy of Sciences and National Research Council at Washington, D. C. The assembly took place on the afternoon of April 27 and the meetings of sections on the morning and afternoon of April 26 and on the morning of April 27. The sections of Geodesy and Volcanology held separate meetings. Joint meetings were held by the sections of Seismology,

Geodesy, and Terrestrial Magnetism and Electricity, the program being devoted to a symposium on geophysical methods in the study of geological structure, and by the sections of Meteorology and Oceanography, the program being devoted to a symposium on interrelations between the sea and the atmosphere and their effect on weather and climate.

The Union was favored by the presentation of a number of papers from members of the national committees of Canada and Mexico. Besides reporting on the progress of governmental activities, these papers were concerned also with the results of researches on the figure and physics of the Earth stimulated by the committees. The active spirit of international cooperation on the part of Canada, Mexico, and the United States was well evidenced in these papers and by the attendance of many visitors during the ninth annual assembly.

The meetings were well attended, and much interest was aroused particularly in the symposia and discussions. This opportunity is taken on behalf of the Executive Committee of the Union to thank most cordially the speakers, guests, and members of the Union for their active interest and participation, making possible the success of the meetings.

J. A. FLEMING,
General Secretary.

REPORTS AND PAPERS

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GENERAL MEETING

(Washington, D. C., April 27, 1928)

REPORT OF DELEGATES OF THE AMERICAN GEOPHYSICAL UNION TO THE THIRD GENERAL ASSEMBLY OF THE INTERNATIONAL GEODETIC AND GEOPHYSICAL UNION AT PRAGUE, SEPTEMBER 3 TO 10, 1927

[*Delegates.*—Louis A. Bauer, William Bowie, J. H. Dellinger, N. H. Heck, Herbert H. Kimball, Walter D. Lambert (Secretary), R. A. Millikan, and Harry Fielding Reid (Chairman) representing the Union; Commander A. B. Cook representing the United States Navy Department.]

Of the thirty-two nations now members of the Union, twenty-seven were represented at the Prague Assembly by their own delegates; several other countries which were prevented by distance or some other reason from sending representatives had delegates from other nations to represent them. About two hundred delegates and guests attended the Assembly. The delegates from the United States were: Louis A. Bauer of the Department of Terrestrial Magnetism of the Carnegie Institution of Washington; William Bowie, N. H. Heck, and Walter D. Lambert of the United States Coast and Geodetic Survey; J. H. Dellinger of the United States Bureau of Standards; Herbert H. Kimball of the United States Weather Bureau; R. A. Millikan of the California Institute of Technology (unfortunately Dr. Millikan, although in Europe, was not able to reach Prague for the meeting); and Harry Fielding Reid of Johns Hopkins University. These seven represented the American Geophysical Union, and Commander A. B. Cook of the Hydrographic Office represented the United States Navy. Professor L. C. Graton of Harvard University also attended the Assembly as an invited guest of the American Geophysical Union. In the organization of the American delegation at Prague, Harry Fielding Reid was elected Chairman and Walter D. Lambert, Secretary.

Dr. Lallemand was reelected President of the International Geodetic and Geophysical Union to serve until the end of the convention in 1931. American officers in the international body include Dr. Bowie, who continues as President of the Section of Geodesy, and Dr. Bauer, who was elected President of the Section of Terrestrial Magnetism and Electricity.

On account of the reduction in the value of the franc, in which unit the quota of the membership states is payable, the present income of

the international body is little more than one fifth of what was originally contemplated. It is now proposed to reduce the nominal fees of the members to one-third the original amount, but to have them paid in the gold franc as the unit. This will increase the present income about three-fourths.

It was proposed that attempts be made to have the International Geodetic and Geophysical Union and the International Astronomical Union meet the same year at places not too greatly separated to make it possible for delegates, living at great distances, to attend them both.

The present convention ends December 31, 1931. The next Assembly of the international body will be held in Stockholm, Sweden, in August, 1930, and steps will then be taken to renew the convention.

The Central Powers have been invited to join the International Research Council and its various unions, but thus far have not responded. Hungary has joined the International Research Council but, for financial reasons, has not joined the unions. Bulgaria has declined both invitations for financial reasons.

As the result of a thorough discussion of the various topics proposed for consideration at the Assembly, a number of resolutions were adopted. The delegation is indebted to H. D. Harradon of the Department of Terrestrial Magnetism for the following translation of the French version of these resolutions, communicated by President Lallemand and Secretary-General H. G. Lyons:

I.—In view of the decision unanimously adopted, June 29, 1926, by the International Research Council at its general meeting at Brussels, according to which the contribution to be paid by each of the adhering countries is to be henceforth calculated in gold francs, the sum originally adopted as the unit of contribution, in each union, to be at the same time reduced in a proportion included between a third and a fifth of the present figure;

Considering that, for the International Geodetic and Geophysical Union, the unit of contribution has been until that time fixed at 2,600 French paper francs, which, in the beginning of 1919, were equivalent to about 1,800 gold francs:

The General Assembly unanimously proposes to replace provisionally, beginning with 1928, this amount by a round sum of 900 gold francs and invites its bureau to bring this resolution to the attention of the International Research Council and of the national committees of the various associated countries.

II.—In view of the desire expressed by the American National Committee of Geodesy and Geophysics to have, in the future, the International

Geodetic and Geophysical Union and the International Astronomical Union hold their meetings the same year at an interval of only a few weeks and in cities not too distant from each other so as to facilitate attendance at these meetings by scientific men interested in the work of both unions;

The General Assembly of the International Geodetic and Geophysical Union invites its bureau to enter into correspondence with the Bureau of the International Astronomical Union for the purpose of carrying out, if possible, the proposal in question.

III.—The assembly reelects unanimously, as president of the union, M. Charles Lallemand, whose term of office, according to article 6 of the statutes, had expired.

IV.—On the proposal of the Section of Geodesy:

The General Assembly recommends that the governments possessing a submarine fleet undertake, as soon as possible, gravity-determinations on board submarines by the new method of Vening-Meinesz—such determinations being of the greatest interest to geodesy.

V.—On the proposals of the Section of Seismology:

(1) The General Assembly recommends that seismological installations be made in the following regions:

(a) In the northern part of Spain and in the Balearic Islands to complete the réseau of Spanish stations.

(b) In New Caledonia and Tahiti to complete the réseau of the French colonies.

(2) At the request of the American Committee of Geodesy and Geophysics, the General Assembly recommends that, wherever it may be possible, observations and studies be made, in common, on the ocean-deeps and on their relations with the bottom-relief, with gravity-anomalies, and with depth of seismic centers.

VI.—On the proposals of the Section of Meteorology:

(1) The General Assembly notes with satisfaction that the published tables of observations made in the upper atmosphere contain results from tropical stations and from stations in the Southern Hemisphere, in particular wind and temperature soundings at Hongkong and wind soundings at Colombo and Dewa in the Island of Ceylon, at seven stations in Brazil, at Pretoria in South Africa, at Melbourne in Australia, and at Apia in the South Pacific; it recommends that this work be continued and developed through international cooperation.

(2) The General Assembly further recommends that, as far as possible, copies of the minutes of the section be made available to meteorologists desirous of carrying out investigations and that a list of persons to whom these minutes should be sent be drawn up by the national committees.

VII.—On the proposals of the Section of Oceanography:

(1) The General Assembly approves the creation of a permanent mixed commission organized with the cooperation of the sections of Seismology and Volcanology for the purpose of collecting all the documents of use for the study of the phenomenon of bores.

(2) The General Assembly approves the creation of a permanent mixed commission organized with the cooperation of the Section of Meteorology for the purpose of studying the influence of polar ice on climates, especially in the Southern Hemisphere.

VIII.—On the proposals of the Section of Volcanology:

(1) The General Assembly, considering that studies of the thermal gradient of the Earth are not only of interest to pure science, but also to industrial applications, recommends that the Italian government kindly intrust to its National Research Council the mission of undertaking such investigations on the volcanoes of Italy and especially on Vesuvius.

(2) In view of the importance to science which is offered by the state of the extinct volcanoes and the lavas of the Aegean Sea, the General Assembly recommends that the petrological laboratory of the University of Athens continue its systematic studies of this subject.

(3) At the request of Professor Ktenas, of the Academy of Athens, it recommends that the new volcano in the Kamenis Islands of the Santorin Archipelago, the eruption of which began August 11, 1925, keep the name of the great geologist Fouqué.

(4) In view of the international interest presented by the measurement of the speed of propagation of longitudinal and transversal waves in solid and fluid magmas near the point of fusion, it recommends that such measurements be undertaken by countries having active volcanoes in their territory and in that of their colonies.

The reports on the activities and meetings of the several sections of the Union will be published in detail separately by the executive committees of those sections. These activities may be summarized briefly as follows:

Section of Geodesy.—Reports of work done in various countries were received. Special reports of work carried out by commissions were submitted as follows: 1) bases; 2) triangulation; 3) precise leveling; 4) geodetic astronomy; 5) deflections of the vertical; 6) intensity of gravity by pendulum; 7) intensity of gravity by other methods; 8) isostasy; 9) variation of latitude; 10) projects.

The most important scientific communication was that of Dr. Meinesz on "Determination of gravity at sea by means of pendulums."

Some of the delegates were not altogether satisfied with the Hayford ellipsoid as the ellipsoid of reference adopted at Madrid and preferred the Clarke ellipsoid of 1880; but many countries are reducing their observations on the Hayford ellipsoid and this will lead to uniformity and will make it easier to connect up the triangulation in adjoining countries. This is a great advantage, and it will be easily possible using Hink's tables to change over to the Clarke ellipsoid should further work make this desirable.

The United States Coast and Geodetic Survey was requested to prepare a manual for the reduction of observations to introduce uniformity in these reductions. The accurate determination of longitudes, repeated, will show many east-west changes in the position of observatories as a result of earth-movements; but it must be remembered that even if such changes are found it will not mean the migration of continents unless observatories scattered over a continent reveal a common movement.

Section of Seismology.—There was discussion of the interpretation of seismograms and the method of reporting; for example, the question of the phases to be reported and the conventional signs to be used to designate them, as well as the question of a standard transmission curve, were brought up. No conclusions were reached, the questions being referred to committees.

The desire was expressed for a list of seismological observatories, and the Section was pleased to learn that Dr. H. O. Wood has that project in hand. Many matters were discussed such as the velocity of propagation of earthquake disturbances, the relation of some magnetic disturbances to earthquakes, microseisms, etc.

Dr. Imamura described his long-period pendulum (two meters or more) and mentioned its records of very long waves in the *P*-phase. Such long waves may not be uncommon but may have been overlooked since short-period instruments magnify long waves very little, their existence being obscured by the more evident short waves. Dr. Imamura reported horizontal displacements at the time of the earthquake of 1923 revealed by a repetition of the triangulation. Instruments for measuring small tilts have been mounted in Japan and have shown tilting a few hours before showing earthquakes. This method is suggested as a means of prediction. Very heavy seismographs appeal to some; Zurich has one of about 20 tons, and Strasbourg has recently had one of 19 tons constructed, it being reported to be extremely sensitive.

Section of Meteorology.—The Leipzig meeting of the International Commission for the Exploration of the Upper Air took place before the Prague meeting of the International Section of Meteorology and discussed

many of the same questions including that of methods to avoid certain duplications of papers. At Madrid £500 were appropriated to publish sample volumes of data regarding the upper air.

The question of units in meteorological work was given a great deal of consideration, and of the twenty-two resolutions[1] adopted by the Section those relating to units took a prominent place. The attention of geophysicists was invited to the advantages of using, where practicable, geodynamic height in calculations and tables. The Bureau of the Section was requested to draw up a report of the various practices of the different sciences comprised within the International Geodetic and Geophysical Union with regard to units of measurements and to invite the cooperation of the bureaus of the other sections of the Union with the ultimate object of a common unitary system for all.

The Section authorized its Commission for Solar Radiation (*a*) to encourage by all possible means the maintenance of an international network of pyrheliometric stations for measuring the intensity of solar energy, (*b*) to include in this network as many high-level stations as possible, and (*c*) to make provision that at the high-level stations especially careful attention be given to the measurement of ultra-violet radiation and the ozone-content of the atmosphere. The work of our delegate Herbert H. Kimball was especially commended, and he was made Chairman of the Commission.

Section of Terrestrial Magnetism and Electricity.—As had been arranged for at the Madrid meeting, the Section occupied itself especially with the discussion of reports from committees. Among the matters discussed were comparison of magnetic instruments, definition of magnetic and electrical characterization of days, terminology, abrupt beginnings of magnetic storms, magnetic properties of rocks, the aurora, and electrical phenomena of thunderstorms.

As the result of the nine meetings of the Section, in which practically all topics proposed in the printed agenda were discussed, thirty resolutions[2] were adopted, many of which were concerned with standards, standard instruments, and nomenclature.

The encouragement in every possible manner of study of correlations between radio reception and magnetic, atmospheric-electric, and auroral activities and solar activity was advocated, although it did not appear that the time had arrived at which any international program could be

[1] For the complete text of these resolutions, see report by Herbert H. Kimball, Monthly Weather Review 55: 387 (1927).

[2] For summary of these resolutions, see Louis A. Bauer, Terr. Mag. 32: 169 (1927).

usefully framed. Among the international committees appointed was one to advance auroral studies and one to consider the best means of promoting research and instruction in the methods of applying the principles of geophysics to investigations of the Earth's crust.

Section of Oceanography.—The Section was especially interested in deep-sea sounding. In this method the French have used very short wavelengths, even shorter than those of sound. The tides were much debated, as also Lambert's report on earth-tides and the mutual influence of earth-tides and sea-tides on each other. A committee was appointed to collect information regarding so-called "tidal waves" and means of limiting the damage done by them.

Considerable attention was given to questions concerned with the attempt to coordinate the activities of the Section with those of other organizations. A recent accomplishment of the Section reported was the preparation of lists of oceanographers and oceanographic institutions throughout the world, these publications being of great value to those engaged in oceanographic work. A committee was formed to consider standardization of oceanographic instruments.

In a group-section meeting of the sections of Geodesy, Seismology, and Oceanography a resolution was adopted regarding ocean-depths which in effect recommended the investigation of these critical areas by the methods of acoustic sounding, gravity-observations above them, and seismologic observations on the adjacent shores.

Section of Volcanology.—Reports were presented on the recent eruptions of Vesuvius and Santorin. Thermal gradients in the Earth's crust were discussed, and countries in which active volcanoes exist were invited to make determinations of this gradient. A joint meeting of the sections of Volcanology and Seismology considered the propagation of earthquake vibrations in the crust with special relations to the neighborhood of volcanoes.

Section of Scientific Hydrology.—The committees of this Section are charged with the study of rivers, lakes, glaciers, underground waters, statistics, and hydraulic utilization of water. These titles explain themselves. It may be added that the Committee on Glaciers takes over the reports on the variations of glaciers in all parts of the world, a task formerly performed by the Glacier Commission of the International Geological Congress.

The transactions of the Third General Assembly of the International Geodetic and Geophysical Union and of its sections at Prague are being prepared for publication by the Secretary-General of the Union and by the respective secretaries of the various sections. These will give in detail

the transactions, activities, and resolutions. The Prague Assembly was by common consent considered the most important meeting yet held by the Union.

A preliminary note on actions pertaining to standards, standard instruments, and nomenclature taken at the Prague Assembly was prepared by Mr. Fleming, General Secretary of the American Geophysical Union, at the request of the United States Bureau of Standards and published in the "Standards Yearbook 1928" of the United States Department of Commerce (p. 20-25).

Copies of Bulletin No 61 of the National Research Council giving the transactions of the eighth annual meeting of the American Geophysical Union held in Washington in April 1927 were distributed during the meeting at Prague. This bulletin was most favorably received and commented upon by the delegates of other countries at Prague. It gave admirable evidence of the activities of the American Geophysical Union and added to the prestige of its delegation.

The excellent facilities afforded by and the many courtesies received from the government and scientists of Czechoslovakia had much to do with the marked success of the Assembly.

HARRY FIELD REID,
Chairman, American Delegation.
WALTER D. LAMBERT,
Secretary, American Delegation.

SCOPE AND GENERAL RULINGS CONCERNING THE PROPOSED PUBLICATION OF BULLETINS ON GEOPHYSICAL METHODS, INSTRUMENTS, RESULTS, ETC., UNDER THE AUSPICES OF THE DIVISION OF PHYSICAL SCIENCES OF THE NATIONAL RESEARCH COUNCIL

DAYTON C. MILLER[1]

One of the major activities of the Division of Physical Sciences of the National Research Council is the organization of Research Committees which shall prepare reports on current scientific subjects, the reports to be published as Bulletins of the National Research Council.

The former Chairman of this Division, Dr. Joseph S. Ames, in cooperation with the American Geophysical Union, originated a most important Committee under the general title "THE PHYSICS OF THE EARTH," with the Chairman of the Division of Physical Sciences as Chairman and the Chairman of the Division of Geology and Geography and the Chairman

[1] Chairman, Division of Physical Sciences, National Research Council.

of the American Geophysical Union as Vice-Chairmen. Under this Committee there are nine Subsidiary Committees and three Sub-Committees, making in effect 11 separate committees each under its own Chairman. Some of the reports are nearly ready for publication and will probably appear within the calendar year. It is hoped that all will be completed by the end of the year 1929.

ORGANIZATION OF THE COMMITTEE ON THE PHYSICS OF THE EARTH

COMMITTEE ON THE PHYSICS OF THE EARTH

Chairman of the Division of Physical Sciences, *Chairman*
Chairman of the Division of Geology and Geography, *Vice-Chairman*
Chairman of the American Geophysical Union, *Vice-Chairman*

Subsidiary Committees

(a) THE FIGURE OF THE EARTH

Chairman, Fred E. Wright
Vice-Chairman, William Bowie

Sub-Committees

(I) GRAVITY, DEFLECTION OF THE VERTICAL, AND ISOSTASY—William Bowie, *Chairman*

The members of this Committee will prepare eleven chapters with titles as follows:

(1) Precise leveling
(2) Base measurements
(3) The determination of g by means of the free-swinging pendulum (land and sea)
(4) The determination of g by means of the elastic properties of confined gases
(5) The determination of g by making use of the elastic properties of solids
(6) The determination of the horizontal component of gravity, the gravity-gradients, and the shape of the Earth determined by observations with the Eötvös balance
(7) The instruments used in geodetic work, their characteristics and design
(8) The determination of the shape and size of the Earth
(9) The place of isostasy in geological research

(10) The place of isostasy in geological research (second chapter)

(11) The proof of the isostatic condition of the outer portion of the Earth by gravity and deflections of the vertical data

(II) TIDES, OCEAN AND EARTH—G. T. Rude, *Chairman*

The members of this Committee will prepare the following chapters:

(1) Introduction
(2) Tidal theory
(3) Tidal computation and prediction
(4) Mean sea-level
(5) Earth tides
(6) Tidal friction

(III) VARIATION OF LATITUDE—Frank Schlesinger, *Chairman*

(b) SEISMOLOGY—James B. Macelwane, S. J., *Chairman*

The matter to be contained in this report is exceedingly varied and has to do with the following:

(1) Dynamics and relative performance of the seismographs
(2) Location and construction of seismographic stations
(3) Interpretation of the records obtained
(4) The depth of the focus, with periodicities
(5) Mechanism and the causes of earthquakes

(c) TERRESTRIAL MAGNETISM—W. F. G. Swann, *Chairman*

The following chapters are being written by the members of this Committee:

(1) Magnetic measurements
(2) Atmospheric-electric instruments and measurements
(3) Ionization of the upper atmosphere
(4) Theories of atmospheric electricity, and terrestrial magnetism

(d) AGE OF THE EARTH—Adolph Knopf, *Chairman*

(e) FIELD METHODS FOR DETECTING UNHOMOGENEITIES IN THE EARTH'S CRUST—E. A. Eckhardt, *Chairman*

Six chapters are being prepared by the members of this Committee as follows:

(1) Gravitational methods
(2) Seismic methods
(3) Magnetic methods
(4) Electric methods
(5) Electromagnetic methods
(6) Geothermal methods

(f) INTERNAL CONSTITUTION OF THE EARTH—L. H. Adams, *Chairman*
(g) METEOROLOGY—H. H. Kimball, *Chairman*
(h) OCEANOGRAPHY—N. H. Heck, *Chairman*
(i) VOLCANOLOGY—A. L. Day, *Chairman*

The Chairman of this Committee has in hand a manuscript from Friedlaender, one from Jaggar, and one from Karl Sapper. There are outstanding possible contributions from Harker, Mallandra, and Lacroix.

At its meeting on April 22, 1928, the Division of Physical Sciences of the National Research Council considered the present status of this work. A formal resolution was adopted instructing the chairmen of the various sub-committees to act as a coordinating committee or board, to determine various general methods of procedure, definitions, units of measurements, and bibliographical references, to insure uniformity in the various reports and treatments of the several branches of the general subject. It was decided that the reports should set forth the present state of knowledge in such form as to be continuously readable, with ample references to the more technical special papers which are available in special publications.

There were no instructions in regard to the final editing of all the reports by one editor, though it would certainly be within the province of the new Board of Editors to make recommendations as to this matter.

RESOLUTION

(Adopted at General Assembly of the Union, Washington, D. C., April 27, 1928)

Be it resolved that the membership[1] of the Union shall not exceed one hundred until such time as a greater number may be provided for.

[1] The total membership of the Union before the passage of this resolution was limited to seventy-five, in accordance with the action taken at the fourth annual meeting April 19, 1923, Washington, D. C.

SECTION OF GEODESY

(Washington, D. C., April 27, 1928)

REPORTS OF PROGRESS

THE HISTORY OF GEODESY IN MEXICO[1]

P. C. SÁNCHEZ

It may be said that the operations undertaken between 1858 and 1861 in the preparation of the topographic map of the Valley of Mexico were the first in Mexico that from their character might properly be termed geodetic. This work was done under the able direction of Francisco Diaz Covarrubias, geographic engineer. The angles were measured with a repeating theodolite and the bases with wooden rods. Although astronomical observations were made at that time in certain towns in the Valley, they cannot be classed as geodetic because of the lack of good instruments and of good star catalogues, but must be considered merely as good geographic observations for locating the corresponding points of the survey on the terrestrial spheroid. Real geodetic work done with the required precision began in Mexico in 1898 under the auspices of the Geodetic Commission, which was organized in that year and whose first director was the geographic engineer, Angel Anguiano.

As it is well known, in 1864 General Baeyer conceived the laudable idea of measuring various meridional arcs in Central Europe and succeeded in organizing what was then known as the "Mitteleuropäische Gradmessung." Because of the importance of the activities of this organization and because of the fact that most of the civilized countries of the world had joined it, the name was later changed to "The International Geodetic Association."

Mexico then became a member of the organization and sent as its first delegate Francisco Diaz Covarrubias, but no work was done until 1898 when, upon the initiative of H. S. Pritchett, Superintendent of the U. S. Coast and Geodetic Survey, it was planned to measure in America a great arc along the ninety-eighth meridian from Mexico through the United States and Canada to the Arctic Ocean, starting from 15° north latitude and extending to the sixtieth parallel, or as far north as might be possible.

When Mexico accepted the invitation to measure that portion of the meridian within her territory, it was proposed not only to undertake the

[1] Translated by Arturo A. Tomelden, International Boundary Commission, U. S.-Alaska and Canada. Translation revised and approved by the author.

work involved in the measurement of the arc but also to establish nets of triangulations of various orders of accuracy to serve as control for subsequent topographic operations, so that a more thorough mapping of the entire republic might be accomplished with all the accuracy required by modern methods. As a member of the International Geodetic Association, Mexico accepted its program of work and resolved to undertake the following in addition to triangulation: precise leveling, geodetic astronomy, and the measurement of the intensity of gravity.

GEODETIC TRIANGULATION

(*a*)—The triangulation of the parallel of Mexico City (19° 30′) consists of a geodetic chain which starts from the Valley Base, situated in the outskirts of the City of Mexico, and which ends at the south tower of the City of Puebla and at San Juan Hill, the latter spot being the locality used by the French Commission which came to Mexico in 1882 to make observations of the transit of Venus, and which determined the astronomic position of the locality.

The horizontal angles were measured with a Troughton altazimuth instrument reading to one second; Bessel's direction-method was used. Zenith distances of all triangulation points were also observed in order that the elevations of the stations might be computed for reducing the angles to sea-level and that data about the topography of the region might be obtained. For the first time the method of least-squares was used with all rigor for computing the most probable directions at each station and for the adjustment of the triangulation. The probable error of an observed angle came out as 1″.722.

The base-lines were measured at night by means of steel tapes 100 or 50 meters in length and yielded a probable error not far from 1 part in 1,000,000.

In the instructions given out by the Director as a standard for these early operations the following occur:

> VI—Care should be taken that the distance between two neighboring geodetic bases shall not exceed 160 kilometers, which is equivalent to saying that two consecutive bases should be, wherever possible, within about one and a half degrees of one another.

At that time the important work of the United States Coast and Geodetic Survey regarding the relative strength of figures was not yet in existence. This later served us as a standard in the location of our bases and in the *a priori* criticism of projected triangulation.

(*b*)—The triangulation along the ninety-eighth meridian west occupied the activities of the Geodetic Commission from 1901 to 1915, in which

latter year connection of the Mexican and the American scheme was attained by observing the quadrilateral *Colombres, Tenacitas, Donna, Rio Grande.*

Dr. W. Bowie, Chief of the Division of Geodesy, United States Coast and Geodetic Survey, in speaking of this connection, expressed himself as follows:

An event of great importance in the history of geodesy was consummated in the spring of 1916 when observations were made at stations on the northern and southern banks of the Rio Grande, which connected the arcs of primary triangulation which had been established in the United States and in Mexico along the ninety-eighth meridian. The connection is interesting to the geodesist because it makes available a very long meridional arc of connected and completed triangulation.

This connection will make available data from which to compute with greater accuracy than heretofore the dimensions of the Earth. This will in itself make the work a notable contribution to science. But of even greater moment is the fact that the connection of the triangulation of the United States and Mexico will enable the latter country to extend to new areas from the ninety-eighth meridian arc geodetic control for surveys and maps in the form of triangulation which can be based on the North American Datum.

This datum had been called the United States Standard Datum previous to the year 1913, when it was also adopted by Mexico and by Canada for their geodetic coordinates. Its designation was changed to the North American Datum when it had thus assumed an international character.

On June 2, 1913, Mr. Pedro C. Sánchez, subdirector of the Comisión Geodésica Mexicana, wrote as follows from Tacubaya, D. F., Mexico, to Dr. Otto Hilgard Tittmann, at that time Superintendent of the United States Coast and Geodetic Survey:

"I have the honor to inform you that the Mexican Geodetic Commission has accepted as the datum for the computation of geodetic positions of triangulation stations in all of the area of Mexico, what is known by the Coast and Geodetic Survey as the 'United States Standard Datum.' As you have previously been advised, the computations which have been made in this office have been based on the Clarke spheroid of 1866."

On June 13, 1913, the Superintendent of the United States Coast and Geodetic Survey replied to Mr. Sánchez as follows:

"I have the honor to acknowledge receipt of your letter of June 2, 1913, announcing the adoption by the Comisión Geodésica Mexicana of the United States Standard Datum and the Clarke spheroid of 1866 as the basis for all triangulation stations established in Mexico.

"A letter recently received from the office of the Chief Astronomer of Canada, who is in charge of the geodetic work of that country, announces that Canada will also use the same datum and spheroid that are used in the United States.

"I take pleasure in announcing that hereafter this datum will be called the North American Datum on account of its international character.

"The adoption of the same datum for practically all of the continent of North America is an event of great importance in the history of geodesy."

An acknowledgment from Mr. Sánchez, dated July 8, 1913, read as follows:

"I have the honor to acknowledge receipt of your letter of June 13, announcing that the United States Standard Datum will be called hereafter the North Ameri-

can Datum on account of its international character, since Canada, the United States, and Mexico have adopted it and the Clarke spheroid of 1866 as a basis for their geodetic work."

In December, 1915, Mr. Pedro C. Sánches, now the Director of Geographical and Climatological Studies of Mexico, in a communication to the United States Coast and Geodetic Survey, suggested that the time was opportune to connect the arcs of the ninety-eighth meridian triangulation in Mexico and in the United States and that he was especially anxious that this should be done as soon as practicable, as he wished to base all the triangulation of Mexico on the ninety-eighth meridian arc, and to have the geodetic coordinates of the triangulation stations in that arc based on the North American Datum.

The Superintendent of the United States Coast and Geodetic Survey informed the Director of Geographical and Climatological Studies of Mexico that he would be glad to cooperate with him in joining the two arcs of the ninety-eighth meridian. Mr. C. V. Hodgson of the Coast and Geodetic Survey, and Mr. Silverio Alemán, of the section of geodesy of Mexico (now under the Bureau of Geographical and Climatological Studies) proceeded to Brownsville, Texas, and made arrangements to observe between the stations on the Mexican and the United States sides of the Rio Grande. Before the connection was made Mr. Hodgson was called away to his work in Idaho, on the Utah-Oregon arc of primary triangulation, and Mr. E. H. Pagenhart, of the Coast and Geodetic Survey, was directed to represent the United States in Mr. Hodgson's place.

The observations were completed successfully early in May, 1916. After the completion of the field-work, the computation and adjustment of the triangulation from Alice southward were made at this Office. In the adjustment there were used the bases measured at Point Isabel, Texas, and Colombres, Mexico, and the Laplace azimuths at Point Isabel and Alice—and at triangulation station Donna. The latter is one of the stations of the quadrilateral connecting the two sections of the arc. Details in regard to the adjustment are given in this report. As soon as the computations had been completed and the geographic positions of the ends of the base-line in Mexico had been placed on the North American Datum, the information needed by the section of geodesy of the Bureau of Geographical and Climatological Studies of Mexico was sent to that office.

Observations Made in 1916 to Connect Triangulation of the United States and Mexico

After the preliminary plans had been perfected by the officials of the United States Coast and Geodetic Survey and the section of geodesy of the Bureau of Geographical and Climatological Studies of Mexico, Mr. C. V. Hodgson, assistant, proceeded to southern Texas and had conferences with Mr. Silverio Alemán, chief of the section of geodesy of Mexico, and they arranged to have signals erected at the two stations Donna and Rio on the United States side, and at Colombres and Tenacitas, the two stations at the ends of the Colombres base line, on the Mexican side of the Rio Grande.

It was decided that Mr. Hodgson would make the observations at the two stations in the United States and that Mr. Alemán would make the observations at the two stations in Mexico and that each would have signal lamps posted and lights shown to the other.

Owing to the obstructions on several of the lines in the quadrilateral formed by the four stations which were to be occupied and the necessity for extending

the height of the signals, it was not possible for the observations on the United States side to be completed by Mr. Hodgson before it became necessary for him to proceed to Utah and start observations on the Utah-Oregon arc of primary triangulation. In order that there might be no danger of a postponement of the work, Assistant E. H. Pagenhart was sent to Texas to relieve Mr. Hodgson.

Mr. Pagenhart completed the observations on the American side of the river on May 3, 1916, and on May 6 he was notified by Mr. Alemán that the observations at the Mexican stations had been completed. On May 8 Messrs. Pagenhart and Alemán had a conference at Brownsville, Texas, at which they combined their observations and found that they were in every way satisfactory.

This meridian-chain traverses the most rugged portion of the Oaxaca Range, a part of the states of Puebla, Vera Cruz, and Hidalgo and ends in the plains of the state of Tamaulipas. It includes 76 stations; the sides vary from 20 to 120 kilometers in length, and it embraces an area of approximately 80,000 square kilometers. The cost of the work was in round numbers $1,200,000.

The angles were observed in general by Bessel's direction-method, except at some of the northern stations at which the Schreiber method was used in addition to Bessel's for the purpose of comparing the two methods and of choosing the more suitable. The conclusion was reached that, because of the climate, Bessel's method was preferable and for this reason the latter method has been followed on all subsequent observations.

The mean error of an observed angle calculated by Ferrero's formula is 1".355.

On most of these triangulation stations the instrument could be set up on the ground. It was only in the northern regions, in the plains of Tamaulipas, that it was necessary to erect wooden towers in order to raise the instrument to a sufficient height to overlook the terrain.

All observations were made during the day, using heliotropes for marks.

(*c*) Geodetic triangulation of Hidalgo was executed for the purpose of providing fundamental control-points for the cadastral operations of that state. The instruments as well as the methods used in this triangulation were identical with those used in the triangulation of the ninety-eighth meridian and in addition one of its sides was connected with this latter triangulation.

In 1915 the old Geodetic Commission of Mexico was reorganized to form part of a new organization called *Dirección de Estudios Geográphicos y Climatológicos* (Office of Geographic and Climatological Studies) as it exists at the present time. The general geodetic program of the present organization is much the same as that of the former except that its activities were widened to include the topography, hydrology, and cartography of the country.

As it was necessary from the beginning to provide geodetic control-points for the various topographic surveys, which were then being made in various states of the republic, arcs of triangulation were arranged for in these states, which for the present remain unconnected with the main geodetic scheme although they will be gradually tied to the main scheme in order to form a homogeneous whole. These arcs of triangulation are as follows:

(*d*) The triangulation of Yucatan is composed of two chains, one of which runs diagonally, crossing the state along its greatest length and extending 250 kilometers. The other runs from north to south from the Port of Progreso to the boundary between the states of Yucatan and Campeche. The two together cover an area of 5000 sq. kms. There are 34 first-order stations, 4 second-order stations, 15 third-order stations, and 111 intersection-points.

This group of trigonometrical points in Yucatan has made possible the topographic survey of that state by the Topographic Section of this office. The complete mapping of the state from the data obtained from the field is at present in process of completion.

(*e*) The triangulation of Sinaloa was planned to make a survey for the contemplated geographic map of that state, and in view of the fact that the cadastral triangulation in that region was well advanced, a fundamental geodetic scheme has been drawn up and partially executed. It crosses the state along its greatest length.

(*f*) The triangulation of Lerma River is a continuation of the triangulation of the parallel of Mexico City towards the west, and it is planned to continue it through the valleys of the Lerma and the Santiago rivers to the Pacific Ocean at the mouth of the latter river.

(*g*) The triangulation of Chihuahua traverses the state from the Durango boundary to Juarez on the United States international boundary. This triangulation is connected with that of Sinaloa.

(*h*) The triangulation of Lower California is based on the quadrilateral San Miguel, Cuyamaca, San Xavier, Cerro Gordo, which connects the American with the Mexican triangulation. This connection was made in 1919 as a piece of international work.

The Mexican triangulation extends from the international boundary of the United States and Mexico to the twenty-ninth parallel and is controlled by the geodetic base at Guadalupe in addition to the side of the quadrilateral mentioned above.

(*i*, *j*)—The reconnaissance is already completed for two chains of geodetic triangulation along the parallels of 19° 30′ and 26° 00′.

The entire field personnel of this office is at present engaged in the triangulation of Sinaloa, Lerma River, Chihuahua, and Lower Cali-

fornia. All of these schemes of triangulation will eventually be connected with the North American Datum and thus with Meades Ranch, just as the triangulation of the ninety-eighth meridian as well as that of Lower California has been already connected at the northern boundary of Mexico with the triangulation of the United States Coast and Geodetic Survey.

Beginning with the triangulation of Yucatan, the method of observations has been changed in that angles are now observed at night by using electric lamps as marks. This innovation is very significant, since it has proved to give better angular closures and, above all, to save considerable time at each station.

The black areas on the sketch-map of Fig. 1 indicate the locations of the arcs of first-order triangulation which have been executed in Mexico, details of which are given above.

GEODETIC BASES

The triangulation of the parallel of Mexico City is controlled by the Valley Base already mentioned, which was measured by Diaz Covarrubias in 1860. Fearing that the position of the monuments marking its extremities might have been shifted by the seismic disturbances which frequently occur in the Valley of Mexico and desiring besides to study the relative precision of measurements made with wooden rods and with steel tapes, the Geodetic Commission of Mexico remeasured the same base in 1900 using for the purpose two 100-meter steel tapes made by Fauth of Washington. The result of the measurement of the base differed from that made by Diaz Covarrubias by approximately two meters, which is 1 part in 4000 of the entire length. This led to a very interesting investigation by Mr. Valentin Gama, then assistant director of the Commission, in which he showed that the anomaly was due mostly to an error in the length of the five wooden rods used by Diaz Covarrubias. The accepted length of this base is 8645.0582 meters.

The triangulation of the ninety-eighth meridian is controlled by five bases namely: Oaxaca Base, 8 km.; Tecamachalco Base, 12 km.; Rio Verde Base, 15 km.; La Cruz Base, 39 km.; Colombres Base, 7 km.

The triangulation of Yucatan has the Progreso and the Valladolid bases, respectively 8 and 12 kilometers long.

The triangulation of Sinaloa is controlled by the Mazatlan and Culiacan bases of 6 and 7 kilometers, respectively, and finally the triangulation of Lower California depends upon the Guadalupe Base, which is about 6 kilometers long.

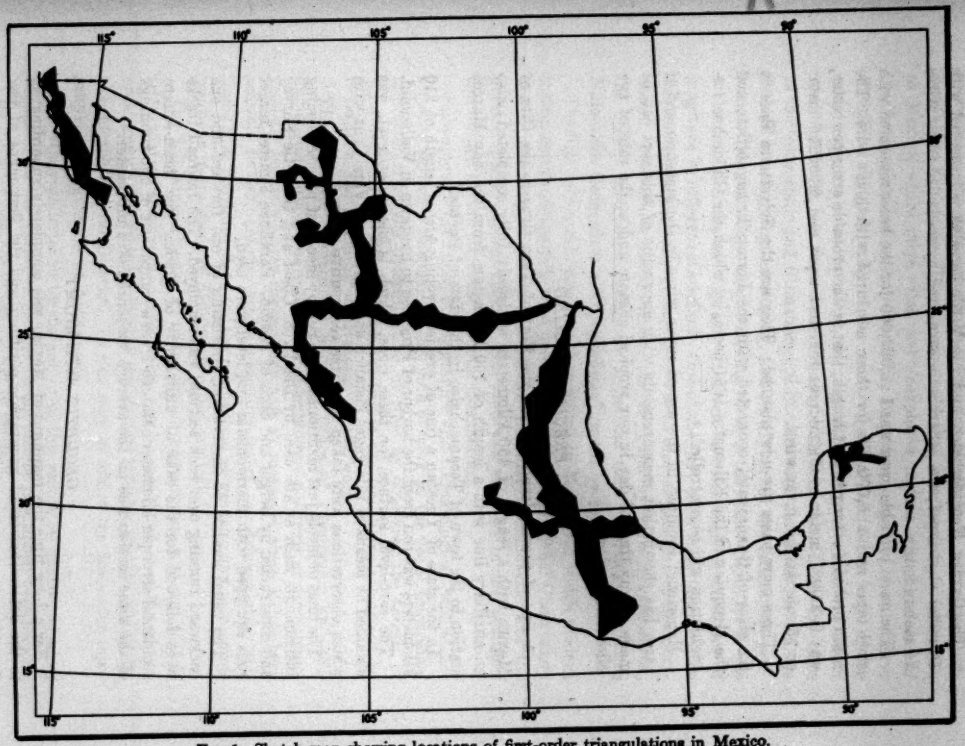

FIG. 1—Sketch-map showing locations of first-order triangulations in Mexico.

The Oaxaca, Tecamachalco, and Rio Verde bases were measured with 50-meter steel tapes; the others were measured by means of invar wires 24 meters long.

The mean probable error was 1:2,000,000 for the bases measured with steel tapes and 1:5,000,000 for those measured with invar wire. The mean probable error per unit length, that is, the probable error per meter, was 0.000031 meter or 31 microns for steel tapes and 0.000015 meter or 15 microns for invar wires.

Three more bases are now planned: They are the Salvatierra Base in the state of Guanajuato, connected with the Lerma Triangulation, and the Meoqui- and the Kilometro-1661 bases, by which the Chihuahua triangulation will be controlled.

Experience acquired in the use of invar wires in the measurement of bases has shown that measurements with apparatus of this sort can be made at any time of day in our tropical climate and at the rate of two kilometers a day.

PRECISE LEVELING

A line of precise leveling from the Port of Vera Cruz to the City of Mexico with a length of 450 kilometers is already fully completed; also an auxiliary line with a length of 100 kilometers from the San Marcos station to the town of Tecamachalco in the state of Puebla.

In the state of Yucatan a line of precise leveling with a length of 210 kilometers was run from the harbor of Progreso to the town of Valladolid.

The zero-level surface for these lines, which is mean sea-level, was obtained by means of tide-gages installed at Progreso and Vera Cruz with which observations were taken for three consecutive years.

The lines of levels just mentioned were run by means of precise-leveling instruments such as are used by the U. S. Coast and Geodetic Survey and constructed by Berger and Sons of Boston. Parafined 3-meter target rods equipped with thermometer and level were used.

The usual method of observation, consisting of one forward and one backward running over each section, was employed. The railroad tracks were followed for the sake of uniformity of grade. The mean-square accidental error per kilometer obtained from a comparison of two runnings of the same section was on the average six-tenths of a millimeter.

GEODETIC ASTRONOMY

For a long time the mapping of Mexico was completely subordinated to the determination of geographic positions and the first maps of the Republic were based on a more or less abundant collection of astronomic

coordinates, the authenticity and accuracy of which it was almost impossible to determine. There is no doubt that in a territory so extensive as Mexico, where there exist vast unexplored regions without means of communication, astronomic methods, if properly applied, would serve to outline the geography of the country; and the extensive work of the early explorers of our territory, the most noteworthy of whom was Baron von Humboldt, was done in accordance with this idea. Later the office of the Geographic and Climatological Studies took charge of the delicate task of investigating, cataloging, and rectifying all the geographic positions of the territory and of reducing them to the same origin, for it was a common practice among early explorers to refer their observations of longitude to different meridians. One of the first tasks undertaken by the Section of Cartography of the office was to discuss and correct the astronomic observations made within the Republic by various authorities; the results have been published under the title "Catalogo de Datos Numericos Geograficos y Topograficos," issued by this Office.

The first astronomic positions determined in Mexico for which modern instruments and methods were used were due to the National Observatory and to the United States and Mexico Boundary Commission and the greatest perfection in work of this sort was attained in the positions determined by the Mexican Geodetic Commission.

Subsequently the Office of Geographic and Climatological Studies has attained further refinement in this kind of work by the use of impersonal micrometers in the determination of time by observing the transit of stars over the meridian and by the use of the time-signals sent out by radio from the principal observatories of the world.

The Geodetic Commission and the Office of Geographic and Climatological Studies have determined numerous positions at astronomic-geodetic points all over the country and by means of these it has been possible to compute the geodetic coordinates of our triangulation stations, thus providing data for the comparison of geodetic and astronomic positions in the study of deflections of the vertical.

The following schemes of triangulation are accurate and are tied to triangulation already discussed. They can be considered as of the second order and are the triangulation of the state of Hidalgo and the triangulation of the Federal District. To this may be added the first-order topographic triangulation of Amecameca.

The study undertaken by the author of this report on the coefficient of refraction in the Valley of Mexico should also be mentioned here because of its intimate relation to the subject of geodesy.

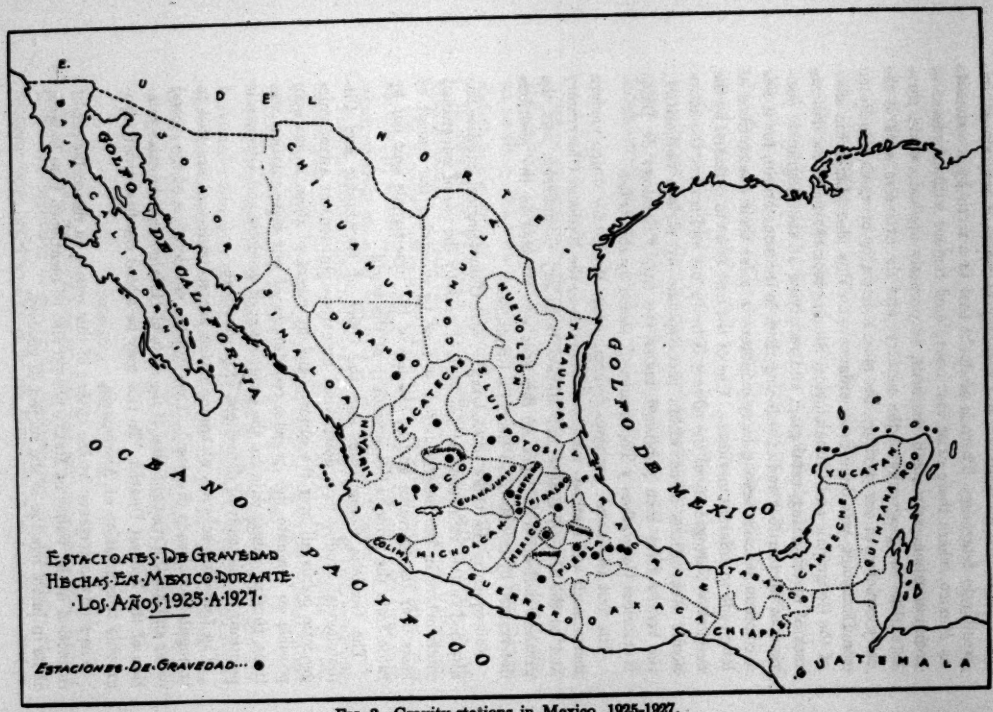

FIG. 2—Gravity-stations in Mexico, 1925-1927.

OBSERVATIONS OF THE INTENSITY OF GRAVITY

In 1912 the first gravity-observations in Mexico were made with a Mendenhall pendulum-apparatus identical in type with that used by the U. S. Coast and Geodetic Survey.

With this apparatus observations were made at the base-station of the Coast and Geodetic Survey in Washington to determine the periods of oscillation of each of the three pendulums of the apparatus. Immediately afterwards another set of observations was made at our Mexican station in Tacubaya to determine the period of oscillation under the new conditions. With the aid of the data obtained from these two sets of observations and with the given value of gravity in Washington the intensity of gravity in Tacubaya was obtained; this value is now considered as fundamental in local determinations of gravity.

At the present time the values of gravity in five circuits of stations have already been determined. The circuits consist of the following points: Tacubaya, Distrito Federal; Puebla, State of Puebla; Tehuacan, State of Puebla; Orizaba, State of Vera Cruz; Jalapa, State of Vera Cruz; Vera Cruz, State of Vera Cruz; Durango, State of Durango; Zacatecas, State of Zacatecas; Colima, State of Colima; Pachuca, State of Hidalgo; Queretaro, State of Queretaro; Leon, State of Guanajuato; Guanajuato, State of Guanajuato; Aguascalientes, State of Aguascalientes; San Luis Potosi, State of San Luis Potosi; Iguala, State of Guerrero; Acapulco, State of Guerrero; and Guadalajara, State of Jalisco. Fig. 2 shows the locations of these points.

Dirección de Estudios Geográficos y Climatológicos,
Tacubaya, D. F., Mexico

PROGRESS OF CANADIAN GEODETIC WORK

W. M. TOBEY

The progress of the Geodetic Survey will be considered under two heads (*a*) general extension and (*b*) investigations.

GENERAL EXTENSION

In 1928 was witnessed the extension and completion of our British Columbia Coast work (see Fig. 1) when it was placed on the North American Datum, thus forming the essential link with the American and Alaskan triangulation. The effects of the inclusion of bases and Laplacian points were noted as the adjustment took place, the net being made to serve as a basis of illustration for the new differential theory of adjustment. This method of adjustment has been used by the Geodetic

Survey of Canada for both triangulation and level adjustments to show the actual effects of new work added to that of a previous year.

In the northern part of British Columbia, where the country is mountainous and where transportation is consequently very difficult, precise traverse and triangulation have been used alternately over a stretch of about 300 miles.

Primary triangulation was extended from the forty-ninth parallel along the one-hundred-and-tenth meridian northwards 150 miles towards Edmonton, thus serving the public interest of this growing district. The net will ultimately proceed westerly towards our British Columbia work, meeting the precise traverse and triangulation that is being extended eastward from Prince Rupert.

The triangulation which covered the eastern part of Ontario has been extended in a northwesterly direction along the Ottawa River and northwards to embrace areas that are highly mineralized, so as to give mapping control for the mining industry in these regions. It has also penetrated the clay belt of Northern Ontario, through which runs the Canadian National Railway system, opening up this valuable portion of the country.

The St. Lawrence River work, embracing a system of triangulation which passes through Quebec, New Brunswick and Nova Scotia, has been completed and adjusted, making a basis for our other triangulation which started therefrom.

For the purpose of determining elevations for various hydro-electric enterprises, numerous additions have been made to our precise-level system. This system is now very stable. It is dependent upon various tidal stations on the Atlantic and Pacific coasts. These tidal stations are Vancouver and Prince Rupert on the Pacific and Halifax, Yarmouth, and Father Point on the Atlantic.

INVESTIGATIONS

Particular attention has been given to the subject of investigations. The Wild transit which was developed by H. Wild of Switzerland, has been used by us with great success. The outstanding features of this instrument are: its lightness of weight (38 lbs.), less than half the weight of the instruments formerly used in Canada; and its peculiar system of optical lenses by which the two circles are read as one mean. The description of the action of the light through these various lenses and the theory relating to the reading of the mean of the two circles has already been explained. It will be sufficient to say that a special feature of this instrument, which has probably not been described before, is the fact that the aperture of the telescope, being large (60 millimeters in

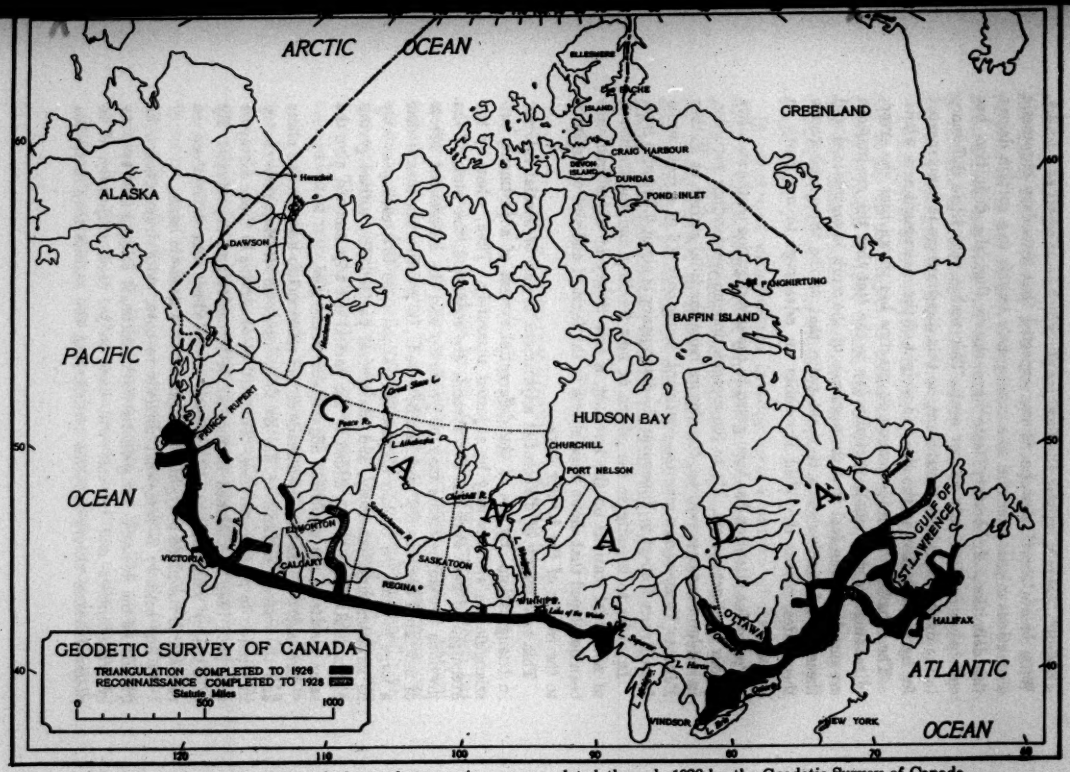

FIG. 1—Chart showing triangulation and reconnaissance completed through 1928 by the Geodetic Survey of Canada.

diameter), bears a ratio to the focal length which is as small as 1 to 3.4. With such a short telescope, it was expected that secondary chromatic aberrations might enter and as a consequence impair to a certain degree the definition. Laboratory tests have shown that the definition has suffered a drop of only 15 per cent. This makes very little difference to the usefulness of the instrument, as this disadvantage is compensated for by the reduction in the size and weight of the instrument as a whole.

The behavior of the instrument in practice has shown that the errors of reading are very small, partially due to the fact that the graduations are on glass. The fact that the accuracy of the work is maintained and the speed of manipulation is about twice that of the three-micrometer theodolites, makes the Wild theodolite an advantage to our work in Canada.

Particular attention has been given to the investigation of the stability of our level-net system. Up to the present time no outstanding variation in sea-level has been noticed, the closure from the tidal station at Father Point to Vancouver, across the continent, being only 0.6 of a foot, while from Prince Rupert to Vancouver the discrepancy is about 0.025 of a foot.

In order to investigate the effects of new leveling and the inclusion of new tidal stations on the level-net, a new theory of adjustment has been developed that shows these effects in the form of additive corrections to the results of the former work.

This new theory of differential adjustment is also of special interest in triangulation. By use of the differential system of adjustment, two triangulation systems may be adjusted separately. Then, when by the execution of new work the two systems are connected, the work of the previous two adjustments may be preserved and the differential effects of new work over the old work can be noted. In practice this means that a large net may be broken up into several parts, so that each part may be adjusted simultaneously, and the several parts finally united giving differential effects, which added to the partial net adjustments, give the same results as the whole net adjustment would give.

Investigation has also been made of the relationship between the plane and the curved surfaces of the Earth in order to develop new theory in relation to precise traverses. This will be of service to those surveyors who have been accustomed to the use of latitudes and departures. By this theory much of the old traverse work, which was determined in relation to the plane only, has been placed on a geodetic basis.

As our country is somewhat difficult to cover with triangulation as quickly as the demands for geodetic work accrue, it follows that systems of triangulation and traverse will have to be used conjointly. The precise-traverse theory involves transferring the results to a fictitious

plane by taking into account the spherical excesses of polar triangles and finally retransferring to a true geodetic basis. It will be of great value to us in our British Columbia work, where precise traverse and triangulation has been run eastward from Prince Rupert. It will also be valuable in Northern Ontario where, due to the level nature of the clay belt, triangulation schemes are very difficult to carry through.

The adoption of the Hayford ellipsoid at the Prague conference naturally brings up the subject of transference of geodetic results from the Clarke ellipsoid of 1866 to the Hayford ellipsoid. This, undoubtedly, is a very difficult problem and one which is very important not only to Canada but to all countries which contemplate changing from one ellipsoid to the other.

In connection with isostatic investigations a number of stations in Ontario, which form part of our geodetic structure, have been observed astronomically for latitude and longitude. Laplacian observations along the precise traverse in British Columbia and at several triangulation stations in other provinces were made, in order to furnish the Adjustment Division with the necessary data for reducing the twist.

Geodetic Survey of Canada,
Ottawa, Ontario

THE GRAVITY-SURVEY OF CANADA

A. H. MILLER

This survey is carried on by the Dominion Observatory, which has so far established 116 gravity-stations, 37 of these being in Eastern Canada and the remaining 79 in Western Canada. The determinations are made with a half-second pendulum apparatus of the Mendenhall type, the apparatus developed and used by the U. S. Coast and Geodetic Survey. The corrections to the chronometers in the field have since 1921 been obtained from the Annapolis wireless signals.

On account of its large area, its varied topography and geology, Canada is a desirable and interesting field for gravity-observations. During 1914 and 1915 a line of gravity-stations was established along the railway from the Atlantic to the Pacific oceans. The work was then discontinued, but has been actively resumed during the last few years. Nearly all the work in recent years has been carried on in the western part of the country. This part was selected as, on account of the nature of its topography and the mapping of it, it was better suited for the first investigations of isostasy. Points at higher latitudes are also more easily reached by either rail or water in this part of the country than in the eastern part.

ISOSTATIC RESULTS

The values of gravity derived from the observations for 69 stations in Western Canada have been computed and theoretical values have been obtained on the assumption of isostasy, as well as by other methods. The isostatic values have been obtained by making use of the tables of Hayford and Bowie.

The isostatic anomalies (an anomaly being the difference, "observed value *minus* computed value") indicate, generally speaking, that the fairly large area, covered by the stations in Western Canada, is in isostatic equilibrium. There are only two regions in which there are moderately large anomalies or in which the anomalies have a very definite tendency. In the Southern part of Vancouver Island there are two positive anomalies of about 0.050 dyne. It is fairly certain that one of these anomalies (at Victoria) is related to the local density of the crust at this point. At the nine other stations on the Pacific Coast the anomalies are small and do not greatly exceed the possible error in the theoretical computation. In Southern Saskatchewan there is quite a definite area of positive anomalies. This area extends across the border into the United States, as is shown from the results of gravity-work in that country.

The part of the country (the mountainous province of British Columbia) which might be expected most readily to indicate in the results departures from isostasy gives values that are very closely in accord with that theory for a depth of compensation (uniform) of about 100 kilometers.

THE SASKATCHEWAN ANOMALIES

The fact that positive anomalies are found in this area is in itself an interesting fact, as first considerations would lead one to expect anomalies of the opposite sign. The part covered by the observations is entirely a region of sedimentary and probably lighter rocks and furthermore has been subject to erosion for a considerable period. It would seem that the anomalies indicate either a lack of equilibrium or else the presence of abnormally heavy rocks beneath the surface. This is not an area in which there is any special reason to suspect a departure from isostasy, but, judging from the Black Hills anomalies in South Dakota, there is reason to suppose that the anomalies in Saskatchewan may be due to abnormal densities. At any rate they indicate something of interest in connection with the structure of this part of the continent. For the Northern Plains of the United States, David White[1] attributes the positive anomalies to the extension of the heavy pre-Cambrian floor

[1] David White, Geol. Soc. Amer. Bull., 35: 250-256 (1924).

which is exposed in the Black Hills region in South Dakota. Following White, the Canadian gravity-observations would seem to confirm his distribution of "unusually heavy basement rocks." In addition they indicate another underground ridge of heavy material extending from Towner, North Dakota, for approximately 300 miles in a northwesterly direction to Saskatoon, Saskatchewan.

RELATION BETWEEN ANOMALIES AND THE GEOLOGY

The results confirm the relations that have already been found by Bowie between the sign of the anomalies on the one hand and the Tertiary and Mesozoic formations on the other. In a limited number of cases where it was possible to secure samples of the rock near the station it was found that the anomalies are related to the local densities. The largest anomaly so far found in Canada is at Victoria, B. C., and it is positive. It is only 75 miles from the largest anomaly in North America, which is at Seattle. The Seattle anomaly is about one-tenth of a dyne and is negative. These circumstances afford a rather striking illustration of Bowie's contention that large anomalies are due to density conditions near the station.

There is a deficiency of gravity over the large Tertiary syncline east of the Rocky Mountains in Alberta. Two stations on the Fraser Delta area in British Columbia have small negative anomalies. The one of these stations having the larger anomaly (Cloverdale, anomaly −.010 dyne) is situated on raised delta deposits. The elevation is apparently due to isostatic readjustment following the final retreat of the ice sheet.[1] According to Johnston the uplift in this region since Pleistocene times has amounted to at least 650 feet. The results, so far, of the pendulum observations over this area may be taken as being in agreement with the conclusions reached from purely geological grounds. No station, as yet, has been established on the recent delta of the Fraser River.

PROGRAM FOR THE FUTURE

It is hoped it will be possible in the near future to complete the office work in connection with the remaining stations already established and to publish a report on all the work that has been done in the country. Reports dealing with the work appear from time to time among the regular publications of the observatory.

[1] W. A. Johnston, Geology of the Fraser River Delta Map Area. Memoir 135, Geol. Surv. Canada, 47, 56, 57 and map.

The field-work will be planned to complete the general survey of the country, but at the same time there will be kept in mind the importance of establishing stations at particular places where conditions may appear to warrant special investigation.

Dominion Observatory,
Ottawa, Canada

PROGRESS OF THE GEODETIC WORK OF THE UNITED STATES COAST AND GEODETIC SURVEY

H. G. AVERS

The geodetic field work of the U. S. Coast and Geodetic Survey during the past year has been confined to triangulation and leveling.

The work on first-order triangulation has been confined almost entirely to the prosecution of the plan to develop the triangulation net east of the ninety-eighth meridian to such an extent that it may form the basic control for all future surveys in this area. Should the results of the new work show that the accuracy of the present geographic positions in this area can be improved, a readjustment of the triangulation will be made similar to that of the readjustment of the triangulation west of the ninety-eighth meridian, which has been reported on in previous meetings of the Section of Geodesy.

An arc of first-order triangulation was extended eastward through southern Minnesota to LaCrosse, Wisconsin, where a connection was made with the Mississippi River triangulation and with the first-order traverse line that had been extended from Green Bay, Wisconsin, during the previous season. From Albert Lea, Minnesota, the arc was extended northward to Royalton, Minnesota, connecting with the triangulation between Fergus Falls and Duluth, Minnesota.

From Martinsburg, West Virginia, an arc of first-order triangulation was extended northwestward to Pittsburgh, Pennsylvania. This arc will be continued until it joins the triangulation of the U. S. Lake Survey near Painesville, Ohio. On this work the new Parkhurst theodolite, described at the meeting of this Section two years ago, received its first field test. The results of the observations were very satisfactory, the average closure of the 64 triangles being 0.81 second.

It will be recalled in connection with this instrument that it was necessary to have the horizontal circle sent abroad for graduation, as the dividing engines in this country were not capable of graduating with a high degree of accuracy circles of small diameter. Future difficulties of this nature will be avoided, as one of the high officials of the U. S. Bureau

of Standards has announced that their new dividing engine will be placed in operation this summer.

A reconnaissance was made for three arcs of first-order triangulation; the first to extend from the vicinity of Augusta, Maine, to Megantic, Quebec, where a connection will be made with the triangulation of the Geodetic Survey of Canada; the second to extend from the triangulation along the 98th meridian in Nebraska, eastward through Iowa and Illinois to the vicinity of Chicago, Illinois; and the third to extend from Portsmouth, Ohio, northward to the triangulation of the U. S. Lake Survey near Sandusky, Ohio.

A special arc of triangulation was extended along the 100th meridian from the Red River northward about 110 miles. This work was done at the request of the Texas-Oklahoma Boundary Commissioner, who will use the results in fixing this portion of the boundary line between Texas and Oklahoma.

The triangulation in Minnesota is deserving of more than passing notice, since on it were used for the first time the Bilby towers. On triangulation over flat and wooded areas it is necessary to elevate the instrument and the lights upon which the observations are made in order to overcome the curvature of the earth and any obstructions to the line of sight between contiguous stations. This has been accomplished, previous to the 1927 field season, by means of wooden towers of varying heights, erected at the stations. The almost prohibitive cost of lumber in recent years and the fact that a wooden tower can be used at only one station, since it is impracticable to dismantle it and use the lumber again, led Mr. J. S. Bilby, Signalman and Chief of Party of the U. S. Coast and Geodetic Survey, to design a steel tower.

The Bilby steel tower is constructed somewhat along the lines of a windmill-tower. It consists of two structures, both tripods, built entirely separate from each other. The outer tripod carries the observing platform and a superstructure on which the signal light is mounted at a height of 88 feet. The inner tripod, 75 feet in height, upon the top of which the instrument is mounted, extends through an opening in the observer's platform to a convenient observing height.

Fourteen Bilby towers were used in Minnesota during the past season. They have proved very steady and free from vibration even in high winds; it was possible to carry on the observations during a 25-mile wind. The wooden towers are sometimes blown down by a high wind and tests show that they have moved from three to five inches off center after a 50-mile gale, whereas the steel tower moved only three-fifths of an inch.

The cost of a 75-foot wooden tower is about $400, including the building, and it can be used only once. The Bilby tower costs $265 and can

be used any number of times. The erecting, dismantling and moving of the Bilby tower costs, on an average, about $100.

In the one season of their use in the field the towers have met the highest expectations of their designer. At the end of four months of observing, 96 stations had been occupied and the total length of the two arcs of triangulation was 475 miles. The building parties were able to erect, dismantle, and reerect the towers with such rapidity that in no case were they delayed by the building operations.

The first-order level-net of the United States is composed of 53,000 miles of leveling. During the past season more than 2,700 miles of leveling were added to the net. The new lines are located in Maine, New Hampshire, Vermont, Massachusetts, North Dakota, South Dakota, New Mexico, Colorado, Utah, Arizona, and California.

The leveling in California was done at the request of the Advisory Committee in Seismology of the Carnegie Institution of Washington and is located in areas suspected of seismic activity. New lines of levels, aggregating 605 miles in length were run. Portions of old lines aggregating 83 miles in length were rerun. The rerunning of the old leveling did not show any large changes from the previous results, except in the case of a few individual bench-marks that had undoubtedly been disturbed by local causes.

Two adjustments of the leveling in the New England States have been made, one to test its accuracy and the other to provide elevations for the bench-marks. In the first adjustment only the eight complete land circuits were used. The sea-level connections at New York, Boston, and Portland were not used, as it has been found from an adjustment of all the first-order leveling in the United States that there is a decided slope to the mean sea-level surface and that the closures of circuits of leveling involving connections with sea-level, are, on an average, larger than those of complete inland circuits.

The average closure of the eight land circuits is at the rate of 0.068 millimeter per kilometer, whereas the average closure of the two circuits involving the sea-level connections at New York, Portland, and Boston is at the rate of 0.28 millimeter per kilometer, the length of these circuits being considered as the length of the leveling between the tidal stations.

The plane of mean sea-level has been adopted as the reference datum for all elevations determined by first-order leveling. Wherever the plane is connected with, it is held at zero-elevation and the leveling is fitted to it. This treatment of the leveling naturally makes it take larger corrections than its accuracy warrants; nevertheless, the distortion is not sufficient to be noticeable in ordinary engineering operations.

In the second adjustment the plane of mean sea-level at New York, Boston, and Portland was held fixed at zero-elevation, making two additional circuits. In the first adjustment the average correction per kilometer is about 0.1 millimeter, whereas in the second adjustment the average correction per kilometer is about 0.2 millimeter.

The elevations derived from the second adjustment have been assigned to the bench-marks. These elevations are preliminary and will probably be changed by a small fraction of a foot when the New England net is combined and adjusted with the first-order level-net of the United States. Any future adjustment will have little or no effect upon the relative elevations of adjacent bench-marks and the relative elevations of bench-marks several kilometers apart should not be affected appreciably.

Some progress has been made toward the adjustment of the combined first-order level-nets of Canada and of the United States. The results of all of the Canadian leveling have been furnished to the U. S. Coast and Geodetic Survey by the Geodetic Survey of Canada. The data have been assembled and it is planned to proceed with the actual adjustment this summer.

U. S. Coast and Geodetic Survey,
Washington, D. C.

ISOSTATIC ANOMALIES AT MEINESZ'S SEA-STATIONS

C. H. SWICK

On February 15, 1927, just a little over a year ago, Dr. F. A. Vening Meinesz, of the Dutch Geodetic Commission, completed his two-hundredth determination of gravity at sea. This was his final station on the comparatively short trip south of Java which followed his phenomenal trip from Holland to Java, across the Atlantic and the Pacific by way of the Panama Canal. These 200 gravity-stations of Dr. Meinesz really constitute, at present, the entire gravimetric survey of the oceans, as all other and previous attempts to determine gravity at sea, with the requisite accuracy for geophysical investigations, have had almost no success.

Dr. Meinesz's determinations have been made, as you know, with a specially modified form of pendulum-apparatus installed in a submarine. For his first work in 1923 he used an improved form of the Von Sterneck apparatus; for his later work, a new instrument designed by himself. Except for a few stations in harbors, all of his observations have been made with the submarine submerged several meters in order that the apparatus would have only a limited amount of motion due to the waves and swells. Although the instrument is designed to eliminate from the results the effects of horizontal accelerations, only small motions can be

tolerated, much smaller than those of an ordinary surface ship even in calm weather.

The isostatic reductions of Meinesz's sea-stations are being made by the Coast and Geodetic Survey because of the international character of this very important scientific project. Up to the present time, 153 of the 200 stations have been reduced.

The results already obtained are of considerable interest. First of all they show, beyond any possibility of argument, that the oceans are substantially in isostatic equilibrium. The average isostatic anomaly with regard to sign, based on the Bowie formula, is +0.025 dyne for the 153 stations. Without regard to sign the average is 0.041 dyne.

For the same stations the average free-air anomalies, with and without regard to sign, are respectively +0.016 dyne and 0.047 dyne. There are only nine isostatic anomalies greater than 0.100 dyne and the maximum is −0.202 dyne. There are fourteen free-air anomalies greater than 0.100 dyne, eight greater than 0.200 dyne, and the maximum is −0.329 dyne.

Except for the average with regard to sign, the isostatic anomalies are, therefore, smaller than the free-air anomalies. Some will argue, however, that since the average free-air anomaly with sign considered is smaller than the corresponding isostatic anomaly, the oceans are not in isostatic equilibrium. A very fundamental point that may not be realized at first is that the free-air method of reduction for a sea-station is very nearly an isostatic method.

The free-air reduction for a sea-station is really no reduction at all because there is no correction for height of station except for the small amount the submarine is submerged at the time of observation. In the free-air reduction all matter below sea-level is assumed to have normal density. For a sea-station, this amounts to assuming not only that the material in the Earth's crust below the bottom of the oceans has the same density as at the same depth below a land-station, but also that the water itself has a density equal to that of normal rock under a land-station.

In other words, the free-air method of reduction actually implies that the weight of a unit column on a surface deep down in the Earth is the same as that of any other unit column, and this it should be remembered is exactly what the isostatic method postulates. The chief differences between the two methods is that, in the isostatic method, we attempt to compute the effects of the densities as they actually exist in the crust of the Earth and in the water of the oceans; but in the free-air method we really distribute the densities in an artificial manner.

As Dr. Bowie has pointed out, the anomalies at Meinesz's sea-stations would average several hundred units in the third decimal place of dynes

if, for the computed value of gravity, we took account of the actual low density of the water but did not assume a counter-balancing high density in the rock below the ocean-bottoms. In other words, small anomalies over the oceans are only obtained by assuming some form of balancing of unit columns of the Earth's crust and, as the balancing effected by the free-air method is based on an entirely artificial distribution of densities, we have left only the isostatic method as a reasonably logical method for reducing sea-stations.

The study of the anomalies at Dr. Meinesz's sea-stations has brought out some new problems and angles in the reduction of gravity-stations which will undoubtedly result eventually in important improvements in our methods of computing. For one thing, the isostatic anomalies seemed to show a disturbing tendency to be positive over the oceans. Preliminary studies indicate that this may be due, at least partly, to deviations between geoid and spheroid and to slightly erroneous values of the constants of our gravity-formula previously based, by necessity, on land-determinations alone.

We have recently made some rough computations based on a higher density of the normal rock below sea-level than the density on which our isostatic tables are based. Some of the outstanding anomalies, especially for stations over the great deeps, seem to have a tendency toward smaller values when based on this higher density. This change is a necessary one if we are to approximate actual conditions in the Earth's crust, for the normal density of rock below sea-level is surely greater than that of topographic features above sea-level on which the reduction tables in Special Publication No. 10 of the U. S. Coast and Geodetic Survey are computed.

There are many other interesting points about these gravity-stations at sea and further study will undoubtedly be well repaid. This great pioneer undertaking by the Netherlands government, Dr. Meinesz, and the Dutch Navy deserves the highest commendation of the scientific organizations of the whole world. An inspiring beginning has been made in attacking a large problem. The United States and other countries concerned with geophysical questions must not permit themselves to assume that the Netherlands has completed, or can complete, this work without help. Now that a satisfactory apparatus and method have been devised, every civilized maritime nation in the world should devote several months each year with one or more submarines to the task of making a gravimetric survey of the great ocean-areas. An international agreement could be made which would prevent any duplication of effort and make the surveys count most effectively in one complete program.

An article by Dr. Meinesz in the February, 1928, number of the Geographical Journal gives a most interesting account of his work and methods and includes a brief discussion of some of his results.

U. S. Coast and Geodetic Survey,
Washington, D. C.

READJUSTMENT OF THE TRIANGULATION IN THE WESTERN PART OF THE UNITED STATES

O. S. ADAMS

(Abstract)

At the meeting of this organization last year a report on the progress of the readjustment of the triangulation west of the 98th meridian was given. At that time the results of the loop-closures were stated together with the changes of position in the various junction-figures. During the past year the work of fitting the various sections into this framework has been carried on with more or less regularity. We have had from two to six mathematicians engaged upon the work with an average of about three working full time.

I am glad to state that the work of fitting in the main scheme arcs has finally been completed and that all of the first-order work has now been computed on the final datum. These lists of positions on the North American Datum of 1927 are in manuscript and the data for all first-order work in this region are available in this form. It will now be the task to recompute the intersection-points and such secondary schemes as are integrally connected with the first-order work. These computations have been started and some few of the sections have been finished at the present time. This work will now be carried out as rapidly as possible so that the computation of the coast-work may be undertaken. This will necessitate the fitting in of all of the coast-work in the states of Washington, Oregon, and California.

In addition to the computation of these section arcs, the old first-order arc in California has been readjusted introducing Laplace azimuths and holding the data on the 39th parallel and also at the southern end near the Mexican boundary. This computation is to be used in a forthcoming publication on the changes of geographic positions in the earthquake region of California. It is hoped that this publication will be ready for the printer in the course of a few months. Until its appearance no detailed account of the work will be given out by the Bureau since a careful weighing of the results will be required for a proper understanding of their significance.

U. S. Coast and Geodetic Survey,
Washington, D. C.

SYMPOSIUM ON THE FIGURE OF THE EARTH

The second part of the meeting of the Section of Geodesy was devoted to the presentation of four papers in a symposium relating to the figure of the Earth. These are to be published beginning with the July, 1929, number of the American Journal of Science to which reference may be made for the complete papers. The titles and authors follow:

THE FIGURE OF THE EARTH FROM TRIANGULATION

W. BOWIE

THE FIGURE OF THE EARTH FROM GRAVITY-MEASUREMENTS

C. H. SWICK

THE TORSION-BALANCE IN THE DETERMINATION OF THE FIGURE OF THE EARTH

DONALD C. BARTON

ASTRONOMICAL METHODS OF DETERMINING THE FIGURE OF THE EARTH

WALTER D. LAMBERT

SECTIONS OF SEISMOLOGY, GEODESY, AND TERRESTRIAL MAGNETISM AND ELECTRICITY

(Joint meeting, Washington, D. C., April 26, 1928)

SYMPOSIUM ON GEOPHYSICAL METHODS AS APPLIED IN THE STUDY OF GEOLOGICAL STRUCTURE

Six papers were presented in this symposium on geophysical methods as applied in the study of geological structure before the joint meeting. They are published either in full or in abstract in the Journal of Terrestrial Magnetism and Atmospheric Electricity (33: 129-148, Sept., 1928). The titles and authors follow:

THE RELATION OF THE MAGNETIC WORK OF THE UNITED STATES COAST AND GEODETIC SURVEY TO GEOPHYSICAL PROSPECTING METHODS

DANIEL L. HAZARD

GEOPHYSICAL PROSPECTING METHODS USING EFFECTS OF SUBSOIL INHOMOGENEITIES WITH SPECIAL REFERENCE TO MAGNETIC, RADIOACTIVE, AND ELECTRIC METHODS

C. A. HEILAND

DEPTHS OF GROUND-WATER AND OTHER SUBSURFACE FEATURES INDICATED BY EARTH-RESISTIVITY SURVEYS

O. H. GISH

THE EÖTVÖS TORSION-BALANCE METHOD OF MAPPING GEOLOGIC STRUCTURE

DONALD C. BARTON

TRANSMISSION OF ELASTIC WAVES THROUGH SURFACE ROCKS

ROY W. GORANSON

THE ADVANCE OF AN EARTHQUAKE DISTURBANCE

HARRY FIELDING REID

SECTIONS OF METEOROLOGY AND OCEANOGRAPHY

(Joint meeting, Washington, D. C., April 26, 1928)

SYMPOSIUM ON INTERRELATIONS BETWEEN THE SEA AND THE ATMOSPHERE, AND THE EFFECT OF THESE RELATIONS ON WEATHER AND CLIMATE

PROBLEMS RELATED TO SOLAR RADIATION

VARIATIONS OF SOLAR RADIATION

C. G. ABBOT

OZONE IN THE NORTHERN AND SOUTHERN HEMISPHERES

F. E. FOWLE

The above two papers are published in the Journal of Terrestrial Magnetism and Atmospheric Electricity (33: 149-157, September, 1928).

AMOUNT OF SOLAR RADIATION THAT REACHES THE SURFACE OF THE EARTH ON THE LAND AND ON THE SEA, AND METHODS BY WHICH IT IS MEASURED

HERBERT H. KIMBALL

This paper is published in the Monthly Weather Review (56: 393-398, October, 1928).

RELATION BETWEEN EVAPORATION AND HUMIDITY AS DEDUCED QUANTITATIVELY FROM RATIONAL EQUATIONS BASED ON THERMODYNAMICS AND MOLECULAR THEORY

N. W. CUMMINGS

Abstract.—This research is based upon the following assumptions: 1) The fundamental equations of evaporation as published by Bowen[1] and by Cummings and Richardson[2]; 2) the Dalton relation, namely, $E=N(p-P)$ where E is the evaporation-rate in cm. per day, N is a

[1] I. S. Bowen, Phys. Rev., 27: 779-787 (1926).

[2] N. W. Cummings and B. Richardson, Phys. Rev., 30: 526-534 (1927).

constant for given conditions of wind and insolation, p and P are saturated vapor-pressures of water at temperatures of water-surface and of dew-point, respectively; 3) for such ranges of variation as occur in this particular problem, if $w=f(x, y, z)$, then no appreciable error is made by writing $\bar{w}=f(\bar{x}, \bar{y}, \bar{z})$—a customary and unavoidable assumption unless instantaneous values of the independent variables are used instead of average values (the use of instantaneous values is almost always impossible or impracticable, however); 4) for purposes of computation certain numerical values of the independent variables have been adopted, which seem to be reasonably representative of some of the most interesting and important conditions in the United States.

The foregoing assumptions imply that the rate of change of evaporation with respect to humidity is itself a function of R, the ratio of sensible heat carried off by the wind to latent heat swept away by the vapor, and of dR/dP, which in turn are functions of absolute humidity, water-temperature, air-temperature, and barometric pressure. Observations indicate that these quantities are usually so related as to make dE/dP comparatively small, particularly in the summer when evaporation is greatest. This departure from what might be expected is due to counteracting changes in water-temperature which result from changes in evaporation caused by changes in humidity. The direct effect of humidity-changes on evaporation should not be confused with the indirect effect caused by changes in insolation which usually accompany humidity-changes. There may be sometimes relatively large *transient* effects corresponding to changes in heat-content of the water, but these are usually unimportant.

INTRODUCTION

It has long been recognized by engineers concerned with problems of water-supply, by geologists and meteorologists who have undertaken to account for climatic changes, and by meteorologists and oceanographers who are studying present-day phenomena in the atmosphere and hydrosphere, that a clear understanding of the physics of evaporation from open water-surfaces is highly desirable. With this fact in view, Dr. G. F. McEwen, Physical Oceanographer of the Scripps Institution, advised the writer several years ago, to undertake a critical study of this fundamental problem.

It is probably fair to say that every one who has ever thought of evaporation from lakes at all, has thought of it as being greatly influenced by atmospheric conditions, such as wind, humidity, and air-temperature, but especially by wind and humidity. The present writer at first shared that view, and conducted a very extensive statistical analysis with the expectation of finding correlation-coefficients that would express quantitatively the effect of each particular atmospheric variable.

The method employed was the elegant one that had been developed by McEwen and Michael (Proc. Amer. Acad. Arts and Sci., vol. 55, no. 2,

Dec., 1919), and the data were those compiled by R. E. Horton and published in the Monthly Weather Review (p. 553-566, 1921). The data for the month of July were used more than those for other months because during that month evaporation is relatively high.

It was somewhat of a surprise to find that the data showed no appreciable correlation between evaporation and humidity. This lack of correlation could perhaps be partly explained by errors in the observations and incompleteness of the data, but it was quite evident that such considerations would not completely explain it. There must undoubtedly be an actual physical reason that changes in humidity were *not* reflected as changes in evaporation.

This development, together with other considerations, brought about a decision to attack the problem from the standpoint of the first law of thermodynamics. One consequence of this method of working was the formulation of a qualitative principle somewhat analogous to the principle of Le Chatilier, which has extensive applications in physical chemistry, and Lenz's law which facilitates the treatment of many problems in magnetism and electricity.

The new principle respecting evaporation from lakes may be stated as follows: *Whenever there is any change in wind or humidity unaccompanied by a change in insolation, the temperature of the lake-water always changes in such a way as partially to neutralize the effect on the rate of evaporation from the lake surface of the original change in atmospheric conditions.*

This research was initiated under the guidance of Dr. McEwen at the Scripps Institution of Oceanography but was continued at the Norman Bridge Laboratory of Physics of the California Institute of Technology.

The purpose of the present paper is to deduce from equations based on well known facts of thermodynamics and molecular theory, just what the magnitude of this neutralizing effect must be under certain typical conditions.

A brief discussion of the equations that have been derived theoretically and checked experimentally at the California Institute of Technology by Bowen and by Cummings and Richardson will now be given.

FUNDAMENTAL EVAPORATION-EQUATIONS

The following notation will be used: E, evaporation-rate in centimeters per day; I, insolation in calories per square centimeter per day; B, back-radiation in same units as I; S, change of heat-content in calories per day of a column of water having a cross-section of one square centimeter and a depth equal to the average depth of lake; C, a correction for

quantities of heat not otherwise accounted for; R, ratio of sensible heat carried off by the wind to latent heat swept away by the vapor; L, latent heat of water; t, temperature of water-surface; T, temperature of air on windward side of water-body; p, saturated vapor-pressure of water at temperature of water-surface; P, saturated vapor-pressure at temperature of dew-point; N, a coefficient which remains constant for any one lake so long as wind and insolation do not change; w, any dependent variable; $\overline{w}$, average value of w; x, y, z, any independent variables; $\overline{x}, \overline{y}, \overline{z}$, average values of x, y, z; $h = (I-S-C)$.

Evaporation must obviously be determined entirely by the energy that is rendered available for that purpose. This fact is expressed by the equation

$$E = (I-B-S-K-C)/L \qquad (1)$$

where E is the evaporation expressed in centimeters of depth; I is the incoming radiation per square centimeter of surface; B is the back-radiation to the sky; S is the heat consumed in warming the water; K is a correction due to heat derived from the air or given up to the air as sensible heat; C is a combined correction for leakage through the walls of the container, expansion of the water, and, in the case of a lake, for heat carried by flowing water. It is supposed that all the quantities in the numerator are expressed in gram-calories per square centimeter of open water-surface and are to be integrated over the same time-interval as E.* The heat of vaporization of water expressed in gram-calories per cubic centimeter is denoted by L.

It will be convenient to introduce the quantity R, defined by the relation

$$LER = K. \qquad (2)$$

This means that R is the ratio of sensible heat swept away by the wind to latent heat carried off by the vapor. This ratio has been discussed by Anders Ångström, the Swedish meteorologist, who found that it averaged less than 0.10 for the North Atlantic during the forepart of September, 1905. Ångström concluded that R is in general relatively small, but until now it has been extremely difficult to obtain extensive and reliable in-

*It may not be obvious that S and C can be thus expressed, but if the total amount of heat stored in the entire lake or entering by the methods to which C refers, be divided by the lake-surface area, then a definite part of each of these total quantities of heat will be allocated to a column under each square centimeter. By thus centering attention on a column of water having a square centimeter cross-sectional area and a depth equal to the average depth of the lake we make all the quantities in the numerator comparable and can express them in the same units.

formation with regard to this question. However, Bowen has recently given us an equation which makes it possible to compute R from ordinary atmospheric data without knowing either the sensible heat or the latent heat separately. His equation is

$$R=[0.46(t-T)/(p-P)][b/760] \tag{3}$$

where T is the temperature of the air and t that of the water-surface, P the vapor-pressure of the moisture in the air and p the pressure this would have if the air were saturated at the temperature of the water-surface. The barometric pressure in millimeters of mercury is denoted by b. It is obvious that if we center attention on a definite time-interval such as one day then E can be regarded as an evaporation-rate and expressed in centimeters per day.

It is generally assumed by writers on evaporation from water-surfaces exposed to the open air that

$$E=N(p-P) \tag{4}$$

where N is a constant depending on wind, air-temperature, area of water-surface altitude, and anything else which any particular investigator may see fit to include. This equation is based on certain well-known facts relative to diffusion, and it will here be assumed to hold with N constant for any particular lake so long as wind, air-temperature, and insolation do not change. In this paper we are tracing the relation between changes in evaporation-rate and changes in humidity, and hence we can regard all other conditions as constant except in so far as they must change with these two variables.

RATE OF CHANGE OF EVAPORATION WITH HUMIDITY

Eliminating K between (1) and (2) gives

$$E=(I-B-S-C)/L(1+R)=(h-B)/L(1+R). \tag{5}$$

Differentiating this equation with respect to P must give an expression for the rate of change we are seeking. It is obvious from equation (3) that R is not independent of P and, for reasons that will presently appear, B is not either. Hence, substituting h for $(I-S-C)$

$$L(\mathrm{d}E/\mathrm{d}P) = [(1+R)(\mathrm{d}h/\mathrm{d}P-\mathrm{d}B/\mathrm{d}P)-(h-B)\mathrm{d}R/\mathrm{d}P)]/(1+R)^2. \tag{6}$$

It is evident from physical considerations that, in order for the evaporation-rate to change in response to any humidity-change, the water-temperature must change in such a way as to maintain the necessary energy-balance. Several important consequences follow immediately from this fact:

1) $dh/dP \neq 0$ unless we regard I, S, and C as all being constant or as changing in a perfectly compensating manner. Now we always introduce a fallacy by assuming that anything is constant in the open air, but if we think of each symbol as representing the daily average of a quantity whose instantaneous values vary throughout the day then we can without doing violence to observed facts regard h as constant for a considerable number of days. This is equivalent to assuming that so far as the fundamental equations of evaporation are concerned, the function of an average is equal to the average of the function. As a mathematical principle, this is of course not generally true, but its truth is frequently assumed in meteorological discussions because to do otherwise than make the assumption would involve an amount of laborious integrating that would be quite prohibitive even if the requisite data were available, which is generally not the case. In making the assumption we forfeit to some extent the rigor by which the equations were deduced from physical principles, and it is the intention of the writer to investigate as soon as the requisite data are available the magnitude of the error that is thus introduced under certain typical conditions. Experience seems to indicate, however, that this error is very small and since the assumption is customary it will at least enable us to compare deductions which are otherwise rigorous with conclusions which contain this as well as other assumptions which have a far more questionable basis. With this understanding we shall write $dh/dP=0$.

2) When the surface-water temperature changes, the back-radiation must change according to Stefan's law. It has been found that $dB/dt=12$ calories per square centimeter per day per degree.

3) R must change not only because it involves P but also because it involves t and p which, on account of the first law of thermodynamics, are functions of P.

4) A useful relation is obtained by eliminating E and R between equations (3), (4), and (5). Thus

$$LN\{p-P+[(0.46b/760)][t-T]\}=h-B. \tag{7}$$

Differentiating (7) with respect to t gives

$$LN(dp/dt-dP/dt+0.46b/760)=-12. \tag{8}$$

It will greatly facilitate the further handling of the equations thus far derived if we investigate the comparative magnitudes of the various quantities involved in them. Experience shows that R is very seldom as great numerically as 0.3, so the denominator of the right-hand member of (6) may, for rough approximations be regarded as unity, as can also the coefficient of $-dB/dP$.

A fair average value for LE is 250 calories per day per square centimeter and $(p-P)$ may be taken as 10. This makes[4] $LN=25$. Moreover, tables of vapor-pressure show that $dp/dt=1.08$ in the vicinity of 20 degrees, which is a fair average lake-surface temperature, and b may be taken as 760. Thus

$$dP/dt=1.08+0.46+0.48=2.02 \text{ (approximately)} \quad (11)$$

and

$$dt/dP=1/2.02=0.495=0.5 \text{ (approximately)}. \quad (12)$$

We may obtain dB/dP from the relation $dB/dP=(dB/dt)(dt/dP=12/2=6$ (approximately) calories per day per square centimeter per degree which may with fair accuracy be regarded as its constant value.

It remains to evaluate dR/dP, and this can be done by differentiating (3) thus $dR/dP=(0.46B/760)[(p-P)dt/dP-(t-T)(dp/dP-1)]/(p-P)^2$. This is the most variable derivative of all. Usually $(p-P)$ is about 10, making the first term of the numerator about 5, while $(t-T)$ is frequently zero but may be anything from $+10$ to -10. The relation $dp/dP=(dp/dt)(dt/dP)=1.08\times 0.5=0.5$ (approximately) shows dp/dP to be about 0.5, making the second term of the numerator range from $+5$ to -5. Thus the entire derivative may range from zero to $+0.050$ and the entire right-hand member of (6) may occasionally reach -18 calories per day per square centimeter per millimeter of mercury but probably will seldom exceed that figure numerically. Since the evaporation itself is seldom less than 250 calories per day per square centimeter for any extensive interval of time, the change due to one mm. change in P probably is seldom greater than 7.5 per cent. Such a change in humidity is usually about 10 per cent of the humidity.

As the insolation increases, the value of the function $(1/E)(dE/dP)$ will in general decrease, and usually will be less than 7.5 per cent in July. Since this function is a good index of the strength of any correlation that might exist between E and P, it becomes apparent that the chances are rather against finding such a relation in July, because nearly all the humidities lie within a range of 2 or 3 millimeters, thus giving a total range of variation of evaporation due to humidity alone of less than 25 per cent. It is rather to be expected that such a small change would be quite completely masked by variations in other conditions, particularly insolation, if there are changes in insolation which do not correspond to changes in humidity as there usually are notwithstanding some correlation between insolation and humidity.

[4] Actually the average for July is about twice this, but the difference is in such a direction as to render the final conclusion all the more certain.

When the situation is viewed from the meteorological standpoint, it becomes evident that there must be a strong correlation between insolation and humidity because cloudy days are likely to be humid and clear days dry. Since there certainly is an extraordinarily strong correlation between insolation and evaporation, there is likely to be an apparent correlation between humidity and evaporation. It should be very carefully noted, however, that this apparent correlation is not in reality due to the cause generally assigned to it; that is, it is not due primarily to a checking back of the moisture by high humidity, but rather to a shielding of the water-surface from sunshine by the clouds which generally accompany high humidity. If changes in insolation are first eliminated, no strong correlation between evaporation and humidity should be expected in the residuals. This deduction agrees with the result of the above-mentioned statistical analysis, because in that analysis the effect of changes in insolation was largely eliminated before the correlation between evaporation and humidity was run.

It is not unreasonable to suppose that the insolation-effect could have been eliminated with sufficient completeness to obliterate the *indirect* correlation between evaporation and humidity, and yet remain in the data with sufficient strength to mask the very small *direct* correlation. At any rate, whatever the true explanation may be, the facts are that only a small *direct* correlation could have existed and that small one was not found.

Whenever there is a sudden change in humidity, there is likely to be a *transient* change in evaporation corresponding to a change in heat-content of the water. These *transient* changes have very little climatological interest, however, because in the long run they must sum to practically zero. Nor are they important from the standpoint of estimating losses from reservoirs because the time-interval in such cases is usually so long as to make these transient changes quite negligible.

CONCLUSIONS AND APPLICATIONS

From the standpoint of estimating evaporation-losses from reservoirs and from the ocean, the most important conclusion to be drawn is negative rather than positive. Thus there is little or no hope of ever attaining more than mediocre success in calculating evaporation from lakes and reservoirs or from the ocean by the aid of any empirical formula purporting to express a relation between evaporation and humidity.

Before such an equation can be used its empirical coefficients must be determined from observations on lakes. The empiricism rules out the

possibility of determining the coefficients for pans and then applying them to lakes. But since a strong correlation between evaporation and humidity, when insolation is ruled out, is unlikely, it cannot be reasonably expected that the coefficients can be determined accurately. Even if they were once determined the precision of their application would necessarily be impaired seriously by the fact that changes in evaporation due directly to changes in humidity are small in comparison with other changes.

Such success as might reasonably be expected must be due mainly to the fact that humidity is a rough indication of insolation. It is hardly expedient to make use of humidity on the basis of this principle, however, because better indicators of insolation are available.

Of course, when precise estimates of evaporation are desired, humidity cannot be neglected entirely because it enters into equation (5) through R. When, however, only rough estimates are desired, humidity will frequently not be the best variable, nor even one of the best variables, to use.

If $(p-P)$ instead of P alone is used, a higher degree of success might be expected but this requires in addition to the evaluation of N, an *accurate* knowledge of lake-surface temperature, which is frequently not available, particularly when an investigation concerns a proposed lake not yet in existence.

Equation (5) will in general furnish the basis for the best estimate of evaporation that can possibly be made. Even if the requisite data for the application of this equation are not available, it is still quite probable that a more reliable estimate can be made by inferring the missing data from such facts as are known than by attempting to use any empirical equation that has thus far been proposed.

The helpful suggestions that have been offered by Drs. Vaughan and McEwen of the Scripps Institution in the preparation of this paper are greatly appreciated.

APPENDIX

In the following table are presented values of air-temperature, water-temperature, absolute humidity, and evaporation as recorded by Horton. There are also presented results of computations showing the values of $100R$, LE, $-L(dE/dP)$, and $-(100/E)(dE/dP)$. The stations were selected with a view to obtaining the most representative distribution that the data would permit. In all cases the latest possible year was used.

An anomolous condition seems to have existed in North Dakota during July, 1916, for all the stations in that state reported a very extraordinarily high humidity during that one month of that particular year.

Computations based on representative data

Station	Date	T	t	P	p	100R	LE	$-L\frac{dE}{dP}$	$-\frac{100}{E}\frac{dE}{dP}$
		°	°				*calories*		
Akron, Colo.	July 1915	19.4	21.1	11.1	18.8	+10.2	338	15.7	4.6
Akron, Colo.	July 1916	23.9	22.8	9.0	20.8	— 4.3	585	17.0	3.0
Amarillo, Texas ..	July 1916	26.1	22.8	10.4	20.8	—14.6	560	18.9	3.4
Ardmore, S. D....	July 1915	18.9	21.7	10.9	19.5	+15.0	309	22.2	7.2
Edgeley, N. D....	July 1916	22.8	22.8	17.4	20.8	0	295	26.0	8.8
Moccasin, Mont. ..	July 1913	16.7	18.3	8.7	15.8	+10.4	324	16.1	5.0
Moro, Oregon	July 1912	19.4	18.3	8.1	15.8	— 6.6	400	17.1	4.3
Tucumcari, N. M.	July 1912	26.7	22.2	9.9	20.1	—20.3	586	18.6	3.2
			Averages					18.9	4.9

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THE MEASUREMENT OF INSOLATION BY MEANS OF A PAN

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By the principle of the conservation of energy, the energy gained at the surface of a body of water should equal the energy dissipated. Energy can reach a water-surface in three ways: by direct radiation from the sun; by scattered radiation from the sky; and by temperature radiation from the atmosphere. Whereas, the energy can be dissipated in the following ways: It may be reflected from the surface; it may be absorbed and warm the water; it may go into evaporating the water; it may be lost to the atmosphere by convection; it may be radiated to the atmosphere; or there may be conduction through the walls of the container.

These gains or losses of heat energy have been expressed in the formula used by Cummings and Richardson[1] as

$$I=S+LE(1+R)+C+B \qquad (1)$$

where I is the incoming radiation from the sun and sky per square centimeter of surface, corrected for reflection; S, is the sensible heat or the amount going into warming the water; L, is the latent heat of evaporation of water; E, is the evaporation; R is Bowen's ratio, that is, the ratio of heat losses by convection and evaporation; C is the heat lost or gained by conduction through the walls of the container; and B is the effective radiation from the water-surface to sky, or the radiation from the water minus the radiation from the atmosphere.

[1] N. W. Cummings and Burt Richardson, Phys. Rev. 30: 527 (1927).

The value of R has been given by Bowen [3] as

$$R=0.46P(T_w-T_a)/760(P_w-P_a) \quad (2)$$

where T_w is the temperature of the air in contact with the water-surface, in degrees C; T_a the temperature of the air passing over the water; P_w the saturation-pressure of water-vapor at temperature T_w; and P_a is the pressure of the water-vapor in the air.

Equation (1) in a modified form was used in computing the evaporation from a tank after making observations on a heat-insulated pan. We may write

$$I_p=I_t=S_p+LE_p(1+R_p)+C_p+B_p=S_t+LE_t(1+R_t)+C_t+B_t \quad (3)$$

where the subscripts p and t refer to the pan and tank respectively. For convenience we may collect the quantities into the heat-budget Q.

$$Q=S_p+LE_p(1+R_p)+C_p+(B_p-B_t) \quad (4)$$

The quantity (B_p-B_t) may be computed with sufficient accuracy by Stefan's law

$$(B_p-B_t)=aT_p^4-aT_t^4 \quad (5)$$

where a is Stefan's constant, and T_p and T_t are the surface-temperatures of the pan and tank. By observing and computing the pan's heat-budget Q, as well as the sensible heat, convection, and conduction of heat through the walls of the tank, and by computing the back-radiation difference between the pan and tank, it is possible to determine the evaporation of a tank or lake from the observed data of a pan by the following formula

$$E_t=(Q-S_t-C_t)/L(1+R_t) \quad (6)$$

Table 1 shows the results obtained by this method. The actual procedure consists in measuring by means of the pan, the amount of energy available for dissipation by the tank in the items of evaporation, convection, and sensible heat. However, this does not enable the absolute amount of energy reaching the water-surface to be computed, since we have not taken into account the energy radiated from the water-surface to the sky, or that radiated from the atmosphere to the water. We have only considered the back-radiation difference between the pan and tank. We shall now consider the radiation-exchange between the water and the atmosphere in more detail.

It is of interest to go briefly into the results of previous investigators in regard to radiation to the sky. All these results have been derived from the study of radiation from the surfaces of solids on especially clear

[3] I. S. Bowen, Phys. Rev. 27: 779 (1926).

nights, and accordingly, they are not applicable to the problem of determining the radiation from a water-surface on both clear and cloudy nights.

In 1897 Homén[3] published a paper in which he stated the conclusions at which he had arrived from his investigations: If the sky is clear, there will always be a positive radiation from Earth to space even in the middle of the day; if the sky is cloudy, in the daytime there will be a radiation from sky to Earth; in the night time the radiation for clear as well as cloudy sky always has the direction from Earth to sky.

TABLE 1

Place	Pasadena	Fort Collins, Colorado	Pasadena	Murray Lake, San Diego	Crystal Spring Lake, San Francisco
Date	June 23-July 3, 1926	Sept. 15-25, 1926	June 24-26, 1927	July 7-27, 1927	Aug. 10-30, 1927
North latitude	34°.13	40°.58	34°.13	32°.75	37°.46
Altitude, feet	743	5010	743	541	283
Absolute humidity (K)	11.9	6.8	12.3	13.0	10.4
Temperature water (T_w)	24°.3	15°.2	24°.6	26°.5	20°.6
Temperature air (T_a)	21°.0	13°.2	22°.5	21°.9	16°.1
Bowen's ratio (R)	0.193	0.221	0.121	0.165	0.280
Heat budget (Q)*	471.4	199.5	470.1	501.8	387.4
Evaporation calculated*	396.6	182.5	284.3	431.0	302.9
Evaporation observed*	408.3	185.2	306.7	420.7	307.2
Convection (LER)*	52.4	33.8	13.2	70.8	84.6

* These mean values are given in cal/sq cm/day.

More recently Ångström[4] has reported that radiation from a black surface at a temperature between the limits of −30° C and +30° C may be divided into 3 groups of waves: About 25 per cent of the radiation passes through the atmosphere without absorption and is independent of the thickness of the atmosphere and the amount of water-vapor it contains; about 50 per cent is totally absorbed by the thin layer of the atmosphere, probably in the lowest 30 meters at ordinary vapor-pressures; about 25 per cent is subjected to a variable absorption, depending chiefly on the amount of water-vapor present. Also, the energy in all three of

[3] HOMÉN. Der tägliche Warmeneumsatz im Boden und die Warmestrahlung zwischen Himmel und Erde. Leipzig (1897).

[4] A. ANGSTRÖM. Q. J. Met. Soc., 50: 121-125 (1924).

these groups is very nearly proportional to the fourth power of the absolute temperature of the air.

Table 2 gives results obtained by various investigators who studied radiation from metal surfaces on clear nights by actinometric methods.

Now let us see how the value for B, the effective radiation from a water-surface can be computed. The term, I, which represents the radiation from the sun and sky received by the water-surface, can be set equal to zero during the night. We then have

$$-B=LE(1+R)+S+C. \tag{7}$$

TABLE 2

Observer	Year	Place	Height in meters	Mean value radiation in cal/sq cm/hour
Maurer	1887	Zurick	500	7.7
Pernter	1888	Sonnblick	3095	12.1
Pernter	1888	Rauris	900	9.1
Homén	1896	Lojosse	...	10.2
Exner	1902	Sonnblick	3106	11.4
K. Angström ..	1904	Upsala	200	9.3
Lo Surdo	1908	Naples	30	11.0
A. Angström ..	1912	Algeria	1160	10.4

The temperature-radiation from the atmosphere is a function of many variables, for example, the temperature-gradient of the atmosphere, the pressure of the aqueous vapor, the barometric pressure, etc. We have been able to represent the effective radiation from a water-surface by the following relation

$$B=aT_w^4-baT_a^4 \tag{8}$$

where T_w and T_a are the absolute temperatures of the water and the air above it, and b is the quantity which takes care of the fact that the atmosphere is not a perfectly black body. We can determine the value of b from our experiments. We find that for a particular place and over the period which the observations cover, b is very approximately a constant. Observations in Pasadena, Fort Collins, Colorado, in San Diego and San Francisco, covering a period of sixty-two nights gave a value of about six calories per sq. cm. per hour for the radiation from a water-surface.

The following table gives values of b, also H, the mean absolute humidity, B, the radiation per day from the pan and tank or lake, and I, the mean solar and sky-radiation received per day.

TABLE 3

Place	Pasadena	Fort Collins, Colorado	Pasadena	Murray Lake, San Diego	Crystal Spring Lake, San Francisco
Time of observations	June 1926	Sept. 1926	June 1927	July, 1927	Aug. 1927
Altitude, feet	743	5010	743	541	283
Length of observations, hours	240	240	48	480	480
b	0.915	0.861	0.920	0.884	0.853
Absolute humidity (H)	11.9	6.8	12.3	13.0	10.4
Radiation, cal/sq cm/day					
Pan	116.9	131.5	99.6	128.2	146.7
Tank	135.7	170.3	90.8	....	....
Lake	....	....	....	160.6	176.5
Insolation of sun and sky, cal/sq cm/day	607.1	369.8	561.0	662.3	563.9

Thus it is possible to compute the effective radiation of a water-surface at night. Moreover, we notice from the table given above that the constant b does not vary greatly when the experimental conditions are varied over a wide range. Hence, we conclude that equation (8) is valid for both the night and day.

By means of this formula for radiation from a water-surface it is now possible to compute the total incoming radiant energy of the sun and sky from observations on an insulated pan. The values obtained in this way are given in Table 3.

We can also use this method to determine the amount of evaporation from a lake. Conduction losses through the sides and bottom of a lake are small, and the sensible heat of a lake for a very short time or for an entire year is small. Hence when I, the value of the radiant energy of the sun and sky is computed, we have only to determine the average value of Bowen's ratio, and the average air and water-surface temperatures in order to calculate the evaporation from a water-surface. Evaporation is then determined by the formula

$$E = I - aT_w^4 + baT_a^4/L(1+R) \qquad (9)$$

To sum up the results of this method it may be stated that a comparison of the pan-insolation with a recorded insolation by Weather Bureau No. 17 thermoelectric pyrheliometer, which was calibrated by Dr. Kimball with Marvin No. 3 in Washington, November 11 and 14, 1925, showed the pyrheliometer to give a value 4.5 per cent higher than the pan. However, in Dr. Kimball's letter of November 19, 1925, he states that the pyrheliometer-constant is 0.0130 ± 5 per cent, which seems to indicate that the results obtained by the pan-method are as good as could be expected, and are within the limits of the accuracy of the pyrheliometer.

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THE RATE AT WHICH SOLAR RADIATION PENETRATES THE SURFACE OF LAKES AND OCEANS, AND THE RATE AT WHICH THE SURFACE LOSES HEAT AS DEDUCED FROM SERIAL TEMPERATURE-OBSERVATIONS

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THE PENETRATION OF ULTRA-VIOLET LIGHT INTO PURE WATER AND SEA-WATER[1]

E. O. HULBURT

Abstract.—Measurements were made in the ultra-violet spectrum region λ4000 to 2500Å of the light-absorption coefficients of pure water and sea-water and of the molecular absorption-coefficients of aqueous solutions of the principal salts in the sea. There is a close correspondence between the falling off in the transparency of the sea with decreasing wave-length in the ultra-violet and the spectral energy-curve of sunlight. This, together with the very similar correspondence in the case of the transparency of the atmosphere permits the suggestion that the actinic effects of sunlight may have played a part, perhaps more important than has been heretofore recognized, in the constitution of the sea and the air.

PENETRATION OF SOLAR RADIATION INTO LAKES, AS MEASURED BY THE THERMOPILE

E. A. BIRGE AND C. JUDAY

In the course of its studies on lakes the Wisconsin Geological and Natural History Survey has made many observations on lake-temperature.

[1] Published with the permission of the Navy Department. This paper appeared in full in J. Optical Soc. Am., 17: 15-22 (1928).

It therefore seemed advisable to learn how much of the warming of a lake in spring and summer may be attributed to direct insolation and how much is due to the action of the wind. For the study of the penetration of solar radiation into the lakes and of the direct influence of this radiation on their temperatures, an instrument was needed which would measure the total radiation in terms which could be converted into calories readily and accurately. Since the inland lakes differ widely in the color of their water it was impracticable to use instruments whose response is selective to color.

The question is not merely one of curiosity since on its answer depends much of the understanding of the internal economy of the lake. When the study began there was a general notion among limnologists that diurnal temperature-changes even at considerable depths might be due to direct insolation. It was not uncommonly held that the position of the thermocline depends on the depth to which direct solar radiation is delivered in considerable quantity.

A—INSTRUMENTS AND METHODS

The pyrlimnometer and its use.—The instrument employed is a thermopile and galvanometer, called the pyrlimnometer, whose construction and use have been fully described.[1] Two changes in the apparatus have been made recently.

1) The thermal couples were originally made of iron and constantan. They are now made of bismuth and silver, which give nearly twice as much electromotive force. The bismuth-silver couple gave a galvanometer-deflection of 146 divisions of the scale under conditions similar to those in which two iron-constantan thermopiles gave deflections of 74 and 79 divisions, respectively.

2) In the original construction a D'Arsonval galvanometer was employed for reading the thermopiles. This could be used in the boat but was ordinarily kept on shore and connected with the receiver by a cable 100 meters long. At present a Rawson millivoltmeter is used which can be read in the boat on the lake.

The radiation is observed by single meters of depth and observations have not gone deeper than 10 meters. It is only in exceptionally transparent lakes that this depth is reached before the radiation becomes too small to measure with our instrument. The scale of the galvanometer or the millivoltmeter can easily be read to 1/10 of a division; but such accuracy is possible only when the instrument rests on a solid support.

[1] E. A. Birge. A second report on limnological apparatus. Trans. Wis. Acad. Sci. Arts Let., 20: 533-552 (1922).

In a rowboat it is not safe to attempt to measure a swing much smaller than one division of the scale, which corresponds to about 0.5 per cent of the deflection caused by the radiation from the full sun. This is far enough for the investigation of the warming of the lake; though for photographic purposes it is very far above the lower limit.

In general we have attempted to trace the radiation down to a level from which it would be easy to determine the depth at which only one per cent of the energy of the incident radiation would be left.

In April, 1928, the Survey received a more sensitive millivoltmeter of the semi-suspended type. With the same radiation this instrument gives a swing of the needle six times as great as that from the millivoltmeter hitherto used. Two trials on the lake seem to show that the behavior of the needle when the meter is used in a boat is quite as satisfactory as that of the first instrument. This more sensitive instrument will be of especial value in exploring the transmission of radiation in lakes with highly colored waters.

Most of the work of the Survey has been on small inland lakes, where it is easy for a small boat to escape the action of waves and where no permanent swell is found. It is doubtful whether the method which we have found well adapted to such lakes is directly applicable to the ocean or to large bodies of water where the swell makes it impossible to place the receiver at fairly exact depths below the surface.

Two types of glass cover have been used for the thermopile—a flat piece of plate glass and a hemispherical dome. Each has its advantages and disadvantages. The dome, which has been used more than the other form, has the advantage that its readings in air can be compared directly with those of the Callendar sunshine-recorder, and so furnish a base for computing results in cal/cm^2/min. It has the disadvantage in calling for a large correction for observations in water, due to the lens effect of the spherical water-glass surface. The flat cover needs careful correction for the readings in air, since the percentage of radiation transmitted by the glass will vary with the zenith-distance of the sun; but the ratio between readings in the air and in the water is more easily determined. The two instruments are equally good at depths of one meter or more, where the infra-red radiation has been absorbed and where the object of observation is to ascertain the effect of the successive strata of water on the passage of the radiation which remains. All of the observations reported in this paper were made with the bismuth-silver receiver, with the flat cover.

Computation of results.—In computing the results of the readings several corrections have been made and other possible corrections have been neglected.

1) The main corrections have been those needed to determine the ratio between the reading of the instrument in air and that in the water, say at the depth of one meter. The readings of the instrument in air can be calibrated against those of a pyrheliometer or the Callendar recorder and the value of one division of the scale can be ascertained in cal/cm²/min. But this determination will not hold for readings taken in water, since the change in situation and the altered character of the radiation in water changes the amounts of reflection and transmission of the glass. For a true comparison the effect of the cover must be eliminated in both cases. The plate-glass cover transmits about 82 per cent of the incident radiation in air, and the reading in air is corrected accordingly. When a reading is made in water, at a depth of perhaps 100 cm, the reflection from the upper or water-glass surface of the glass is practically negligible; the absorption due to the glass is also very small, since the infra-red radiation has been almost wholly cut off by the water; and there remains the reflection from the lower or air-glass surface of the cover. This at normal incidence is about 4.25 per cent; and, as an approximate total correction, 5 per cent has been added to the reading. The percentage given in Table 1 for the amount of energy present at the depth of one meter is based on the readings thus corrected.

2) The length of the path taken by the direct radiation of the sun in reaching a given distance below the surface is greater or smaller according to the altitude of the sun. The distance below the surface of the water at which the radiation has passed through a unit of length (say one meter) is equal to the cosine of the angle of refraction of the radiation at the time of observation. In making this correction, therefore, the zenith-distance of the sun at the time of observation is determined and also the cosine of the corresponding angle of refraction. The amount of radiation observed at the successive meters of depth is plotted on coordinate-paper, usually as percentages of the readings in the air. A smooth curve is drawn through these points and on this are marked the depths corresponding to the cosines. These points show what the readings would be if they had been taken with the sun in the zenith, assuming that all radiation comes direct from the sun. The ordinary effect is to increase by one or two per cent the amount of radiation remaining at one meter, and to increase slightly the per cent of transmission in the successive meter strata.

In general this correction lies within the ordinary range of variation of the readings. The observations at the various depths are usually in

good agreement but they are never exactly identical and the reported result is the mean of several readings at each depth. Under all ordinary conditions there may be a variation of several per cent in the value of the radiation from the sun during the course of observations and the thermopile responds promptly to such a variation. There are also innumerable particles suspended in the water which are not distributed with exact uniformity, and as these drift across the field of observation they offer a varying resistance to the passage of the light. If, therefore, the matter concerned a reading at a single depth near the surface, taken near the middle of the day in summer, it would hardly be worth while to correct for the cosine. But the situation is quite different when observations are taken either at early or late hours of the day, say before nine A. M. or after three P. M.; or when observations are taken in early spring or late fall; or when it is desired to trace the penetration of the radiation to considerable depths. In such cases the correction is necessary and it is better to reduce all observations to a common denominator by applying it. This has been done in Table 1.

3) No correction has been applied for the value of the radiation from the sky except for one case noted later (p. 73). The amount of this radiation during hours of sunshine is not likely to be less than 16 per cent of the total received.[2] The per cent of sky-radiation reflected from the surface of the lake is considerable, determined by Schmidt[3] as 17.3 per cent if equal amounts of radiation are assumed to come from equal areas of sky. Under the same assumption the sky-radiation passes through one meter of water in reaching an average depth of 84 cm below the surface. Thus the diffuse radiation from the sky suffers greater losses by reflection than does the direct radiation from the sun; it also meets with greater losses in its transmission through the successive strata of lake-water. A small correction might well be applied to the data on this account, but it seems practically impossible to do anything with sky-radiations under the conditions of observation in a small boat. The person of the observer cuts off part of the sky when readings are taken in the air, and the boat shades a large part of the sky when the receiver is lowered into the water. For purposes of computation, therefore, addressed to single series of observation all radiation is treated as direct.

4) In treating our observations we have not ordinarily considered the amount of radiation reflected from the surface of the water. We have compared the radiation found at a depth of, say, one meter with that

[2] H. H. KIMBALL. Variations in total and luminous solar radiation, etc. Mon. Weath. Rev., 47: 769-793 (1919).

[3] W. SCHMIDT. Ueber die Reflection der Sonnenstrahlung an Wasserflächen. Akad. Wiss. Wien., 117: 73-89 (1908).

found in the air and have included loss by reflection with the other much greater losses in the upper meter. Whenever it has been necessary to consider reflection we have computed it on the basis of the amount reflected from the surface of smooth water and have assigned no value to the effect of waves. So far as our observations go, waves do not make a noticeable difference in the amount of energy reflected.

On numerous occasions a breeze has come up or has disappeared during the course of a series of readings, but no observable change has ever been noted, owing to the presence or absence of ripples or waves on the surface, other than that owing to the varying depth of the water above the receiver. Readings cannot be made when waves are so large as to toss the boat about; but work has been done on Lake Mendota under all practicable conditions and no correlation has ever been found between the presence of waves of any size and the amount of radiation present at the depth of one meter or at any lesser distance below the surface.

Several experiments have been made to test the effect of waves on reflection from water-surfaces. The receiver was placed in a tub of water about 15 cm below the surface and was there exposed to the sun; waves were made by the clapper of an electric gong. This covered the surface of the water with small waves that caused a play of light and shade on the bottom of the tub and over the receiver, such as ripples produce on a sandy bottom. When the surface of the water was smooth the sun caused a galvanometer-deflection varying from 118 to 125 divisions of the scale during the experiment. The production of waves caused a very small decrease in the deflection, not easily measured exactly, since some unsteadiness was caused by the constant and rapid play of light and shade over the surface of the receiver and by the varying depth of the water, both due to the waves. But the reduction was less than one division of the galvanometer-scale; and, therefore, if there was any more radiation reflected from these waves than from the smooth surface, the increase was less than one per cent.

In other similar experiments the waves were caused by wind from an electric fan. These wind-caused waves, or at least the larger ones, should have been trochoidal, while those made by the electric gong were probably sinusoidal. The same effect was produced as in the other experiment—a very small reduction in the reading of the galvanometer, estimated at about 0.7 or 0.8 of a division of the scale. We did not attempt to determine whether this small loss was due to increased reflection or to other causes. No difference could be detected due to different elevations of the sun, which was between 36° and 58° during the various experiments. Differences in the average depth of the water over the receiver produced no observable effect.

It will be seen that we have made no direct study of reflection, but so far as conclusions can be drawn from our observations on the variation of radiation received below the surface, it is not necessary to take into account the changes in form of the surface due to waves. In this our conclusions agree with those from the computation of Soret on the effect of sinusoidal waves on reflection from a water-surface.[4] Further reference to this matter is made on page 75.

B—OBSERVATIONS ON WISCONSIN LAKES

In order to illustrate the results of our studies with the pyrlimnometer we give in Table 1 certain of the more essential data for a few of the lakes which we have examined. All of them are small inland lakes, lying in depressions of glacial outwash or moraine. All except Devils Lake are in the group of lakes found in the northeastern part of the state. The list includes several lakes of the type which is commonly found in Wisconsin and also lakes whose water offers extreme cases both for clearness and for stain.

Crystal and Webb lakes stand first among the clear lakes. They are small and rather deep lakelets (20 meters and 13 meters respectively); which have neither inlet nor outlet; which are without marshy margins; which lie in a flat sandy outwash plain and receive practically no surface or ground-water except through a sand-filter. Devils Lake (14 meters deep) lies between sandy moraine ridges to north and south and has quartzite cliffs along its sides. At the other extreme for color come Mary and Turtle lakes. Their water is so deeply stained by extractives from peat marshes that it resembles a weak tea.

Per cent of total incident radiation found at depth of one meter.—The maximum amount of the total incident radiation at one meter depth was found in Crystal Lake, where it was nearly 40 per cent. It was slightly smaller in Webb Lake. These figures are to be compared with the amount theoretically possible at that depth. This is computed to be about 48 per cent, basing the computation on the absorption-data given by Aschkinass[5] and the normal curves of solar energy given by Abbot and Fowle.[6] It should be noted that the comparisons are not exactly on the same basis, since no allowance has been made in case of the lakes for the extra amount reflected from the surface due to part of the radiation coming from the

[4] C. Soret, Influence des vagues sur la lumiére reflechie par une nappe d'eau. Arch. Sci. Phys., Genève, 4-4: 530-539 (1897).

[5] E. Aschkinass, Ueber das Absorptionsspectrum des flüssigen Wassers, u. s. w., Ann. Physik Chemie, 55: 401-431 (1895).

[6] F. E. Fowle, Transparency of aqueous vapor. Astroph. J., 42: 394. Also mss. data.

sky. This correction would somewhat increase the percentage found at one meter. It seems, therefore, that the water of these lakes is practically free from stain and that there was only a small amount of suspended matter in the water at the time of observation.

Devils Lake, Clear Crooked Lake, and Trout Lake on one occasion, showed that more than 30 per cent of incident radiation was transmitted to the depth of one meter.

At the other extreme come Lake Mary with 6.3 per cent and Turtle Lake with 4.2 per cent at one meter. Turtle Lake has a little less stain than Lake Mary, but more plankton, which accounts for its smaller transmission. Spectrophotometric studies of the water of Turtle Lake in 1914 and 1915 showed that one meter of the carefully filtered water transmitted only 11 and 13 per cent of normal incident radiation. In this extreme case of Turtle Lake the radiation reaching one meter is less than one-tenth as great as that present in pure water.

Next to these extreme cases comes Adelaide Lake into which Lake Mary discharges, and in which there is about twice as much radiation present at one meter. Its water is also much stained. Then come a group of lakes whose water has considerable stain—from 14 to 26 points on the platinum-cobalt scale. These are Kawaguesaga, Lone Canoe, Wild Cat, and Wolf lakes. As all these have considerable plankton, the reading at one meter varies accordingly. The observation on Kawaguesaga Lake shows a higher per cent at one meter than would be expected, but the water was unusually free from suspended matter on the day in question, as is shown by the reading of Secchi's disc.

Lakes with stain giving readings of 6 to 8 points on the scale are very numerous in Wisconsin. They ordinarily show percentages at one meter ranging from 20 to 30, the amount depending very largely on the amount of suspended matter present. Trout Lake offers typical cases from a lake with rather small quantities of plankton. Spider Lake shows the effect of great growths of plankton, coupled with much vegetable debris. White Sand Lake shows the same situation, but in less degree. One meter of filtered water from lakes with a color of 6 to 9 transmits from 30 to 35 per cent of the incident radiation.

Too much emphasis must not be placed on the exactness with which the percentages found at one meter are stated in Table 1. The figures ordinarily depend on several readings which are in good agreement. But small waves may cause unsteadiness in the radiation falling on the receiver; the sun may vary from minute to minute; and the depth cannot be guaranteed to a millimeter when the receiver is suspended by a line over the side of the boat. The figures are carried out to one decimal place, but without expectation that the observations are equally exact.

Transmission of radiation through the successive one-meter strata.—The columns in Table 1 which are headed "Per cent of transmission"

TABLE 1—*Transmission of solar radiation by Wisconsin lakes*

Lake	Date	Transparency m	Color	Cal./cm²/min	Per cent 100 cm	Transmission				One per cent at m.
						1 m 2 m	2 m 3 m	3 m 4 m	4 m 5 m	
Adelaide	Aug. 5, 1927	3.1	38	1.06	11.7	30	37	..	..	3.4
Big	July 26, 1926	3.4	8	0.72	18.8	50	..	..	..	5.3
Blue	June 30, 1926	4.9	8	1.05	28.5	64	64	67	66	8.7
Clear Crooked	July 19, 1927	3.9	6	1.05	30.6	57	58	59	59	7.5
Crystal	July 22, 1926	8.8	0	1.05	35.3	78	80	80	84	17.4
Crystal	Aug. 17, 1926	9.5	0	0.76	35.4	75	81	78	80	18.7
Crystal	July 19, 1927	10.7	0	1.08	35.8	72	77	79	83	18.8
Devils	June 3, 1926	10.9	0	1.03	30.2	62	72	72	73	11.2
Kawaguesaga	July 7, 1926	4.2	14	0.87	29.4	57	57	66	66	8.3
Lost Canoe	Aug. 2, 1927	4.3	18	1.28	21.1	57	62	60	63	7.4
Mary	July 12. 1926	2.0	100	1.36	6.3	39	..	..	..	3.0
Muskellunge	June 29, 1926	4.2	0	1.09	27.0	60	65	69	70	8.2
Plum	July 14, 1926	3.4	8	0.94	23.9	59	62	63	..	7.7
Star	Aug. 2, 1926	4.1	6	0.73	25.7	55	66	65	64	8.2
Spider	Aug. 5, 1927	2.0	8	1.21	11.3	40	40	40	..	3.6
Trout	June 29, 1926	5.3	6	1.28	26.5	63	67	69	71	10.0
Trout	July 22, 1926	5.6	6	1.09	32.2	59	60	69	69	9.0
Trout	Aug. 7, 1926	5.1	6	0.86	25.1	56	58	69	68	8.0
Trout	Aug. 14, 1926	5.0	6	0.86	24.7	62	62	65	68	8.8
Trout	Aug. 24, 1926	5.3	6	0.96	25.6	57	57	65	68	8.0
Trout	Aug. 26, 1926	5.3	6	0.88	23.0	61	65	65	69	7.9
Trout	June 23, 1927	3.7	6	1.08	23.5	61	60	..	..	7.2
Turtle	Aug. 5, 1927	1.7	91	1.22	4.2	18	..	..	..	1.9
Webb	Aug. 13, 1927	8.0	0	0.81	38.5	72	74	77	78	15.0
White Sand	July 23, 1926	2.6	8	0.83	18.7	52	53	..	..	5.5
Wild Cat	July 11, 1926	2.6	16	1.09	15.8	28	37	..	..	3.6
Wild Cat	June 26, 1927	2.4	18	1.06	16.3	38	37	..	..	3.9
Wolf	July 19, 1927	2.4	26	0.79	12.9	22	28	..	..	3.0

Notes to Table 1: *Transparency* is measured by a Secchi's disc 20 cm in diameter; *Color* is measured by the U. S. platinum-cobalt scale. 0 means that there is no brownish or yellowish tinge in the water; *Cal/cm²/min* refers to radiation received at the time of observation on a horizontal surface; *Per cent 100 cm* states the per cent of total radiation received on a horizontal surface at the depth of 100 cm below the surface of the water (the amount observed at 100 cm below the surface is corrected for the effect of the glass cover of the receiver and also for the cosine of the angle of refraction of the direct rays of the sun, see p. 64); *Per cent of transmission*, in these columns the observed per cent is corrected for cosine, radiation being assumed to be normal to surface of lake and all of it is assumed to come direct from the sun (fractions of one per cent are rounded off); *One per cent at meters*, the figures show the approximate depth at which is found one per cent of the radiation present at the surface.

show how much of the radiation present at the top of the stratum named is to be found at the bottom. For the sake of brevity the term *transmission*

will be used to mean *percentage of transmission of radiation through a stratum of water one meter thick.* In cases where the readings are carried down only to the depth of two or three meters, the reason is ordinarily that there was little radiation left at that depth and the limit of accurate reading was reached. In some cases, such as Big Lake, work was interrupted by cloud, but the partial series had characters which made it worth preserving.

The one-meter to two-meter stratum almost always has a smaller transmission than deeper strata. This is due to one or both of two causes. The plankton is likely to be more abundant in the upper meters and thus offers greater obstruction to light. The effect of water—quite apart from stain—on radiation is to cut off rapidly all radiation from wave-lengths in the spectrum greater than 0.600μ. So long, therefore, as much energy is present from that region of the spectrum the percentage of transmission will increase with depth, as is the case in pure water. In lakes with some stain and much plankton there may be little or no difference between the transmission of the one-meter to two-meter stratum and those below, and this condition is ordinarily found in Lake Mendota, as well as in many other lakes of southern Wisconsin.

The highest observed transmission was in Crystal Lake, where over 80 per cent per meter was found at depths of two meters or more. Observations were carried down to 9 meters without finding an average transmission beyond 83 per cent. No other lake reached 80 per cent, though Webb Lake showed 78 per cent. Devils Lake was the only other lake which plainly exceeded 70 per cent, though Big Muskellunge Lake touched 70 per cent and Trout Lake came very near it in the deeper strata reported in Table 1 and passed 70 per cent between 5 meters and 10 meters. These figures should be compared with a transmission of 90 per cent in the one-meter to two-meter stratum of pure water and 91 to 94 in the other strata down to 5 meters. These results are computed from Aschkinass' data on transmission and the solar energy-curves of Abbot and Fowle.

At the other end of the series stands Turtle Lake which transmitted to two meters only 18 per cent of the little energy which reached one meter. This condition was due to water which is deeply stained and has much suspended matter. Wild Cat and Wolf lakes are the only other cases where transmission was less than 30 per cent. These lakes have considerable extractive stain in the water, but probably the abundant plankton is responsible for much of the loss in transmission. Lost Canoe Lake offers a case of a lake whose water has much the same amount of stain as Wild Cat, but in which the transmission was much greater.

Trout Lake showed a marked increase of transmission at 3 meters in all observations of 1926. This was not found in a series taken in 1918,

when the transmission did not exceed 70 per cent to depths of 9 meters. On June 29, 1926, readings extended to 10 meters and the transmission gradually rose to 72 per cent. Such a rise is not improbably present in other cases also.

Spider Lake has an almost uniform transmission of 40 per cent. This is a case where mechanical obstruction by plankton and debris is an important agent in cutting off the radiation. Lake Mary shows a transmission surprisingly high in comparison to the low value at one meter. Observations on this lake were interrupted by cloud and it is not certain that later ones will confirm the stated transmission of 39 per cent. But at one meter there is little radiation left except that to which the stained water is most transparent. However, we should not look for a higher transmission in Lake Mary than in Adelaide, which is less stained and into which Lake Mary discharges. The record of Lake Mary is kept in the list chiefly on account of the low per cent present at one meter, which was definitely ascertained.

In lakes like Trout, Clear Crooked, Blue, Kawaguesaga, Plum, and White Sand the percentage of transmission lies within the range of that found in the great majority of Wisconsin lakes which have been studied. One expects to find in an ordinary lake a transmission of 50 to 65 per cent, varying with the amount of stain present and especially with the abundance of plankton.

Thickness of stratum to which the solar radiation is delivered.—The last column in Table 1 shows the approximate depth at which one per cent of the total solar radiation may be found. It is plain that most of the radiation which gets into an inland lake remains in the upper strata of the water. In the extreme cases practically none is transmitted to greater depths than 2, 3, or 4 meters. In such lakes the direct heating effect of the sun is confined to a very thin stratum. An instructive case of this kind is offered by Lake Mary. This lakelet is almost circular, about 120 meters in diameter and 22 meters deep. It is almost completely surrounded by trees and hills so that the wind has very little chance to mix the water. The effect of the sun is rapidly cut off, as the temperatures show. On August 21, 1926, the temperature in the upper water was as follows: 0 meter, 18°4 C; 1 meter, 17°8; 2 meters, 17°5; 3 meters, 12°0; 4 meters, 7°8; 5 meters, 4°8; thence slowly falling to 4°2 at 10 meters. This condition may be compared with that of Turtle Lake, which lies close to Lake Mary on the same drainage system, and which has water of the same type. The sun has perhaps even less direct effect on temperatures but the lake is about two kilometers long and the wind has much influence. The temperature of the water at the depth of 5 meters in July

and August is about the same as that of the surface and at 10 meters a temperature of 13° C or more is found.

In all but a few of the lakes named in the table less than 5 per cent of the radiation falling on the surface of the lake reaches a greater depth than 5 meters. Crystal and Webb lakes are the only conspicuous excep-

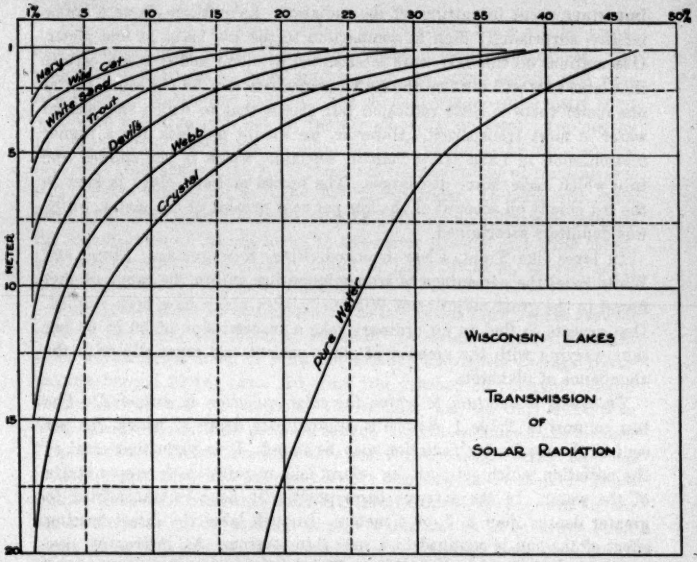

FIG. 1—Transmission of solar radiation in Wisconsin lakes. (Radiation is computed in calories per square cm per minute, being assumed to be direct and to come from a sun in the zenith; curves show per cent of total radiation at the surface of the lake found at given depths; curve for pure water is computed from the transmission data of Aschkinass and the normal solar-energy curves of Abbot and Fowle for direct radiation, air-mass 1.5, and precipitable atmospheric water 0.5 cm.)

tions. In Webb Lake nearly 12 per cent of the total incident radiation is found at 5 meters, and in Crystal Lake there may be transmitted as much as 16 per cent to that depth. In Devils Lake 5 per cent was present at a depth of 6.1 meters.

In general, therefore, there is little risk in continuing downward the curves representing the passage of the radiation through the lake, until

the depth is reached where only one per cent of the total would be found. The results are shown in Table 1 and also for a few of the lakes in Figure 1. In Crystal, Blue, Devils, and Trout lakes direct observations extended to 8 or 10 meters and in most of the others the curves do not go far beyond the observations.

In the ordinary run of lakes the limit at which one per cent is found lies between 7 and 9 meters. It may lie as high as 2 meters (Turtle Lake) and in many cases of lakes with much plankton it may be near or even above 5 meters. Such a situation is present in lakes where Secchi's disc is visible to depths of 3 meters or less; though in this as in other cases there is no close correlation between visibility of disc and penetration of radiation.

In general, therefore, the energy of the direct radiation from the sun is delivered to the strata of water which are included in the epilimnion of a small lake, to the region whose temperature in summer is kept substantially uniform by the wind aided by the alternation of day and night.

In the very transparent lakes the situation is different. Crystal Lake, for instance, is 20 meters deep and the thermocline in August may begin at the depth of 9 meters. At that depth nearly 8 per cent of the total radiation may be present. The surface of such a lake will receive about 60,000 cal/cm^2 during the period April 15 to August 15. Thus nearly 5,000 cal/cm^2 might be transmitted to the deeper water of such a lake by direct insolation—an amount sufficient to raise the temperature of the lower water by several degrees.

These statements and the figures of Table 1 are based on the assumption that the incident radiation is normal to the surface of the water, a condition never found in these latitudes. For Lake Mendota, which lies in latitude 43°, there has been computed the mean path in the lake of the solar radiation received by its surface during what may be called the warming period—April 15 to August 15. Correction has been made for reflection and for radiation from sky and cloud. It works out that during this period the radiation passes through 100 cm of water in reaching the depth of 86 cm. The northeastern lakes are about 3° north of Lake Mendota and, therefore, radiation would pass through 100 cm of water at a depth somewhat less. But no serious error will be made in assuming that the situation is not essentially different from that at Madison; and that the depth at which one per cent of incident radiation is present must be correspondingly modified in order to show the seasonal average. This depth, assuming the conditions of transmission, etc., as shown, would be 86 per cent of the depth stated in Table 1.

Amount of energy present as light at various depths. The discussion has thus far been based on the total energy received by the surface of the

lake, including not only light but also ultra-violet and infra-red radiation. It is possible, however, to use our observations as a basis for general statements regarding the amount of energy present as light at various depths in a lake. Practically all of the infra-red radiation which comes from wave-lengths of the spectrum greater than 0.762μ (the *A*-line) is cut off by one meter of pure water. There is little energy in the solar spectrum derived from wave-lengths less than 0.360μ and this is also rather rapidly absorbed by water. Between 0.360μ and 0.762μ lies a fraction of the total energy which varies with the zenith-distance of the sun and with other variable factors, but which ranges from 50 per cent to 55 per cent for zenith-distances of the sun less than 60° or air-mass 2. About 88 per cent of the total radiation received by a lake during the warming period comes when the sun is at zenith-distances less than 60°.

The general situation will, therefore, be correctly stated if all radiation present at the depth of one meter or more is assumed to come wholly from the visible spectrum as defined above. If the per cent of total radiation found at such depths is doubled the result will show approximately the per cent of the light-energy that is left. Thus in Crystal Lake there may be present at the depth of 5 meters about 32 per cent of the incident energy which comes to the surface in the form of light; 12 per cent at 10 meters; and more than 2 per cent at the bottom of the lake. It may be repeated that this statement refers to energy as measured in cal/cm^2. Such a form of statement may be convenient in discussing certain biological questions, such as the depth to which light penetrates with enough energy to make plant growth possible. Webb Lake for instance is about 13 meters deep and about 2 per cent of the energy of the luminous part of the spectrum might be found at the bottom, even under the average conditions of insolation. In fact, the moss *Drepanocladus* is found growing on the bottom even in the deepest water.

The Survey has determined the transmission of filtered water from a considerable number of lakes for the different wave-lengths of the visible spectrum.[1] These data have been combined with the observations on total radiation so as to show the general nature of the color of the light reaching various depths. But since these studies on the spectrum relate chiefly to lakes in southern Wisconsin, they will not be further discussed here.

Transmission of radiation by strata of water thinner than one meter.—In the studies reported in this paper no attempt has been made to secure accurate data on the transmission of radiation by thin strata of water. For the purposes of our studies on lake-temperatures the significant data

[1] W. B. Pietenpol, Selective absorption in the visible spectrum of Wisconsin lake-waters. Trans. Wis. Acad. Sci. Arts, Let., 19: 562-593 (1918).

hardly begin before the depth of one meter is reached. Still further, the accurate study of transmission by thin strata of water is a matter for the laboratory rather than for the field, where it is not possible to measure exactly the thickness of the stratum examined. However, we have usually taken readings at 25 cm and 50 cm below the surface of the water, more as guides for use in plotting that part of the transmission-curve which lies close to one meter than as part of an investigation of the upper meter itself. Some of the results found at 25 cm are not without interest as giving a general notion of what happens in the water close to the surface. Our observations show that as much as 57 per cent of the total radiation delivered to the surface may be present at the depth of 25 cm in Webb Lake and in Devils Lake. In Crystal Lake 55 per cent was found on one occasion and 50, 48, and 47 per cent on three others. Trout Lake on six dates gave an average of 47 per cent with a minimum of 41 and a maximum of 52 per cent at 25-cm depth. In Turtle Lake only 20 per cent was found at 25 cm and 28 per cent in Lake Mary.

If each lake listed in Table 1 is counted only once the mean result for 17 lakes is 42.3 per cent at 25 cm. On the same basis the same lakes give 30.2 per cent at 50 cm and 20.6 per cent at 100 cm. None of the readings reported under this heading have been corrected for the path of the radiation in the lake. The correction would add somewhat to the percentage present but would not alter the relative value of the data from the several lakes and various depths.

The transmission of 25 cm of pure water may be computed from the solar energy-curves. It appears from these that pure water transmits to the depth of 25 cm about 60 per cent of the total solar radiation and about 83 per cent of the radiation received from wave-lengths smaller than 0.762μ. This computation is made for an air-mass of about 1.5, and for 0.5 cm of precipitable water. Thus the clearest lakes found in the field transmit almost as much as does pure water and the most deeply stained waters transmit only about one-third as much.

Shelford and Gail[1] (p. 161) find that the "surface-transmission" of sea-water for light is small. Under "surface" they include the surface-film and the "few centimeters to which it was necessary to submerge the (photoelectric) cell." The amount of light thus shut out is not less than 26 per cent and may be as much as 67 per cent. The percentage may also vary between the amounts stated above in the time of three minutes. The statements refer to light received on a photoelectric cell which is not sensitive to radiation from wave-lengths greater than 0.600μ.

[1] V. E. Shelford, and F. W. Gail, A study of light penetration into sea-water, etc. Pub. Puget Sound Biol. Sta. III, 65: 141-176 (1922).

It is probable that the "few centimeters" of water included a variable number, but this should make little difference in the amount of light transmitted.

Bigelow* refers to Shelford and Gail's results as due to the action of the "surface-mirror" by which the light is "reflected or shut out." He concludes that "about 50 per cent of the solar radiation . . . . may be expected to warm" the water (p. 675).

We have not worked on salt water nor have we ever employed the photoelectric cell. We are hardly in a position, therefore, to discuss these results. We mention them in order to state that we have not had similar experiences in our work on inland lakes. There has been no noticeable irregularity or rapid change in the transmission of radiation by surface-water; and the differences between observations on different lakes and on the same lake at different times are such as can be referred to variation in color, plankton, and so forth.

Wisconsin Geological and Natural History Survey

PROBLEMS RELATED TO SURFACE-WATER TEMPERATURE

RELIABILITY OF DIFFERENT METHODS OF TAKING SEA SURFACE-TEMPERATURES

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OCEAN SURFACE-WATER TEMPERATURES—METHODS OF MEASURING AND PRELIMINARY RESULTS

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In studying the climatic conditions of America, it appeared that the temperature of the water in the North Pacific might have an important bearing on the development and movements of the high- and low-pressure areas that play the predominate rôle in the character of the weather, especially during the winter season, over a large part of North America, and in 1920 steps were taken to organize the work so that the temperature-data could be collected.

*H. B. Bigelow, Physical oceanography of the Gulf of Maine, Bull. Bur. Fish., 40: 511-1027 (1927).

An examination of existing methods at the time showed that there were two different sets of temperatures obtained, one by the officers on deck and the other by the engineers in the engine-room: in the former, the quartermaster by means of a canvas bucket drew up on deck a sample of water and obtained its temperature with an ordinary thermometer uncorrected for instrumental error and generally reading to 2° F: in the latter, the engineer on duty obtained the temperature of the water circulating through some of the pumps with a similar type of thermometer.

Through the cooperation of the Canadian Pacific Ocean Services the sea-water temperature as recorded in the engine-room logs of the vessels in the North Pacific were copied from 1915 and continued until 1926 as a preliminary investigation. The data thus collected were arranged in five-degree quadrangles for each month of the year, and although the readings were subject to considerable error, not only in the thermometers themselves but in the methods of reading them, yet they furnished valuable information as to the prevailing temperatures in the North Pacific.

At the same time that the logs were being copied tests were made as to the best type of thermometer to use, its location and the degree of accuracy required.

As the method with the canvas bucket or of letting water from a faucet pour over the thermometer could not be relied upon to give sufficiently accurate results for scientific purposes, and as the introduction of a new type of thermometer involved extra work for those who had to take the observations, it was essential that the method should not only be reliable but should require a minimum of time to take an observation. The only way to obtain this accuracy and reliability was to leave the thermometer permanently in a well that was always at the temperature of the sea-water, so that the thermometer could be read at any time without having to wait for it to become steady. Such a well could be obtained by inserting a pipe in the intake to the condensers just inside the main valve, or by putting a block of copper with a hole in it for the insertion of the thermometer against the side of the ship and lagging it well so as to fully protect it from the temperature of the room. The simplest and easiest place is of course the intake; but the intake is from 20 to 30 feet below the water-line in modern vessels and it was not known then whether there would be sufficient mixing to that depth to give a fairly accurate temperature of the surface-water. A well on the inside wall of the ship could easily be placed at any depth below the surface, and Waidner, Dickinson, and Crowe[1] while investigating the temperatures in the vicinity of icebergs in 1912 found that the inside wall of the vessel gave

[1] Bull. Bur. Stand., 10: 267 (1914).

the water-temperatures at that point provided the thermometer was sufficiently insulated from the temperature of the room.

Over the greater part of the North Pacific the sea-water temperatures are fairly constant and probably never vary more than two or three degrees from the normal; a variation of five degrees would be very great. Thus a thermometer reading to only 2° F, as is the case of the ship thermometers, would be utterly useless for meteorological purposes so that it was considered advisable to obtain instruments that could be read to 0°.2 F.

As for the type of thermometer it was obvious on account of the ease with which inaccurate readings can be obtained with an ordinary thermometer, and the difficulty of reading it if it is placed in a well in the intake, that some kind of indicating or distance-thermometer would have to be used if reliable observations were to be obtained. Two types were investigated, the resistance-thermometer and the distance-thermograph.

For the first, a device similar to a Whipple indicator with a platinum thermometer was used; and by having it graduated in degrees it was possible to read the temperature directly to 0°.2 F by merely pressing a button and turning the dial which moved the slide along the bridge-wire until a balance was obtained. The platinum wire was wound on a bobbin which was heavily insulated and put in a brass tube: in the final form the lead- and compensation-wires were connected through a lead-covered cable to the indicator so that there was no danger of the insulation breaking down, because of salt water getting on it. The indicator was securely fastened on a shelf on the wall of the vessel a short distance from the thermometer. The brass tube fitted closely into an iron pipe which was inserted in the intake to the condenser.

Although the instrument was simple to operate and could be read quickly, yet a great many difficulties especially with insulation had to be overcome before consistent readings could be obtained.

Two of these instruments were made up and were used to see if it was possible to place the well on the side of the vessel instead of at the intake, by taking comparative readings of the thermometers at approximately the same level. It is a simple matter to have a platinum thermometer wound on a thin disk and placed against the wall of the vessel as was done by Waidner, Dickinson, and Crowe, yet this could not be done with a thermograph-bulb; consequently, one of the platinum thermometers was placed in a well, as shown in Fig. 1. The copper block was about 1½" square with a hole drilled, as shown, to take the thermometer. The face of the copper was placed flush and soldered to a lead sheet which was screwed to the face of the iron castings. The casting was made to

fit between two ribs of the ship and was about 16″ by 12″ by 3″ inside. The box was filled with mineral wool for insulation and made water-tight so that the wool would not get damp. This box was securely fastened to the side of the ship with the copper block pressed hard against the wall and the edges cemented so as to insulate the box as well as possible from the engine-room temperature. There was, however, unmistakable evidence that the thermometer was affected by the temperature of the engine-room.

Facilities were not available at the time to pursue this investigation any further and in the meantime Dr. Brooks[1] had shown that the temperature obtained at the intake gave quite accurately the surface-temperature as obtained from the first six or eight inches below the surface. The observations of Harvey,[2] however, on the temperature at the surface would indicate that at the first opportunity this point should be carefully investigated. Although it was merely a matter of pressing a key and turning a dial until the galvanometer showed no deflection, yet the engi-

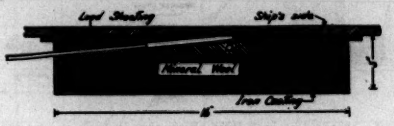

FIG. 1—Well containing platinum thermometer.

neer on duty had to take the observations when he could find the time and it necessitated extra work. Moreover, the instrument was difficult to keep in order and was not a success in the conditions under which it had to be worked.

The second type of instrument was the distance-thermograph from which a continuous record of the temperature was obtained. In trying out this method and getting the range, a mercury-in-steel thermograph with a wall-type recorder having a range of 100° F was installed through the cooperation of the Canadian Pacific Ocean Service on one of their boats plying between Vancouver and Hong Kong. The bulb which was heavily plated with copper was inserted directly in the intake of the condenser but the copper plating was not sufficient to prevent electrolytic action ruining the bulb. The life of the thermograph, though brief, was long enough to demonstrate its superiority over other methods and it was permanently adopted as the standard instrument for obtaining sea-water temperatures; another advantage is that the engineers desire to have

[1] Mon. Weath. Rev., 54: 241-254 (1926).
[2] J. Mar. Biol. Assn. United Kingdom, 13: 683-687.

them. The final method of installing the bulb in the intake is shown in Fig. 2.

The well containing the bulb, consists of a copper pipe having an inch-standard-pipe thread so that it can be very easily inserted into the intake. The bulb is then put into the well and secured with the nuts and packing shown in Fig. 2. There is, however, the possibility of water used about the engine room getting into the openings at *A*, *B*, or *C*, thus in time destroying the capillary; but this can be prevented by filling the openings with good cement.

The recording part which is of the usual thermograph-pattern is simply fastened securely to a shelf, between two of the ribs of the boat where it is in a safe place, and out of the way but easily accessible. It is so placed that about 10 or 15 feet of capillary is sufficient. The trace has never shown any effect of the vibration of the boat. The charts have to be of the best quality, otherwise the constantly high humidity in the

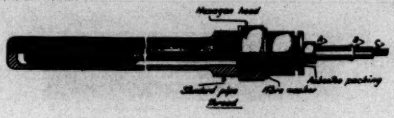

FIG. 2—Method of installing thermograph-bulb in the intake.

engine-room will cause the ink to run. One batch of charts had to be rejected on this account.

It was found that the temperature in the North Pacific on the steamer lanes was between 35° and 85° and the thermographs were obtained with this range. As the work extended, however, some of the vessels traversed regions that had a range from 40° to 90° and others from 30° to 85° or more. As these regions include the North Pacific and the equatorial waters of the Pacific and the West Indies it would appear that practically all ocean-temperatures likely to be obtained would come within the limits of 30° and 90° and this range of 60° has been finally adopted as the standard in the Canadian Service.

THERMOGRAPH OBSERVATIONS UP TO 1927

In Fig. 3 the heavy black lines marked by arrows show the routes actually followed by the different vessels on which thermographs have been installed. On the Northern Pacific route from Vancouver to Yokohama and Hongkong, thermographs have been in use for five years on the SS "Empress of Russia" and for the greater part of that time on the

SS "Empress of Asia" and "Empress of Canada"—all of the Canadian Pacific Ocean Services. More recently a thermograph has been installed on the SS "Aorangi" of the Canadian Australasian Line on the route from Vancouver to Auckland and Sydney. On the Atlantic, ocean-thermographs have been installed on the SS "Canadian Fisher" and

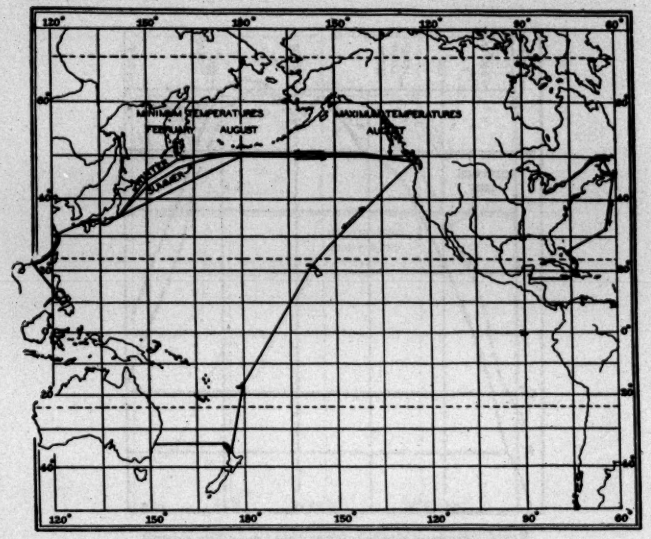

FIG. 3—Routes of vessels equipped with thermographs.

"Canadian Forester" of the Canadian Government Merchant Marine on the route from Montreal or Halifax to Bermuda and the West Indies. On these latter ships, owing to the fact that the temperature-change at the boundary of the Gulf Stream is large and sudden, the thermographs have been equipped with daily instead of weekly charts. Preliminary results indicating the general features of the temperature-distribution are all that have been obtained as yet along the last two routes.

6

Central Pacific.—Figure 4 shows the average temperatures over five-degree quadrangles for two voyages between Vancouver and Auckland, as an indication of the general temperature-distribution along this route. In order to eliminate to some extent the effect of seasonal variation during the time of the voyage, the figures plotted are the averages of the south-bound and northbound trips. A decided fall of temperature at the

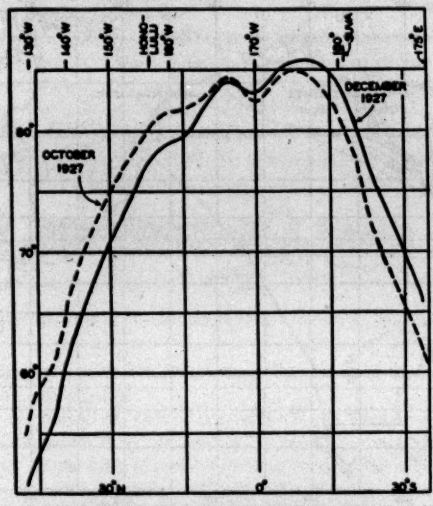

FIG. 4.—Average water-temperatures over five-degree quadrangles between Vancouver and Auckland.

equator itself is very noticeable, and is a feature which will require examination when sufficient records are obtained.

Northwest Atlantic and Gulf Stream.—The primary object in obtaining records on ships on the route from Canada to the West Indies is to find the variation in the boundary of the Gulf Stream, and therefore the records from the area between Nova Scotia and Bermuda have been plotted in half-degree quadrangles. Figure 5 shows the record of one voyage along this route, and is given here as an example of the results expected. On the return voyage in this case a very marked discontinuity

of temperature was found as the Gulf Stream was left behind, the original record showing a drop of 13° F in five miles.

North Pacific.—The records for the North Pacific from 1923-1927 have been averaged for each five-degree quadrangle from longitude 124° west to 142°.5 east, using the quadrangles from 127°.5 to 132°.5, etc., so that position 125° west and 50° north is the center of the first. This division of the quadrangles is particularly advantageous in this particular

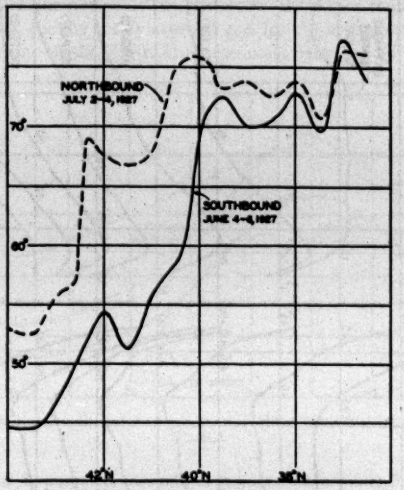

FIG. 5—Water-temperatures obtained in voyage between Nova Scotia and Bermuda.

case, since for the greater part of the journey from Vancouver to Yokohama, the route lies close to the 50th parallel of latitude. These records have been tabulated by weeks, using the division of the year into 52 weeks as suggested by McEwen, giving a definite observation for about every second or third week for the greater part of the five years. Then smoothed weekly normals have been formed and used for drawing normal curves and curves of departures from normal. This method of tabulation has proved very satisfactory for the region east of longitude 170° east, where the variations are comparatively slow both in longitude and in time. In the warm water nearer to the Japanese coast, however, where large varia-

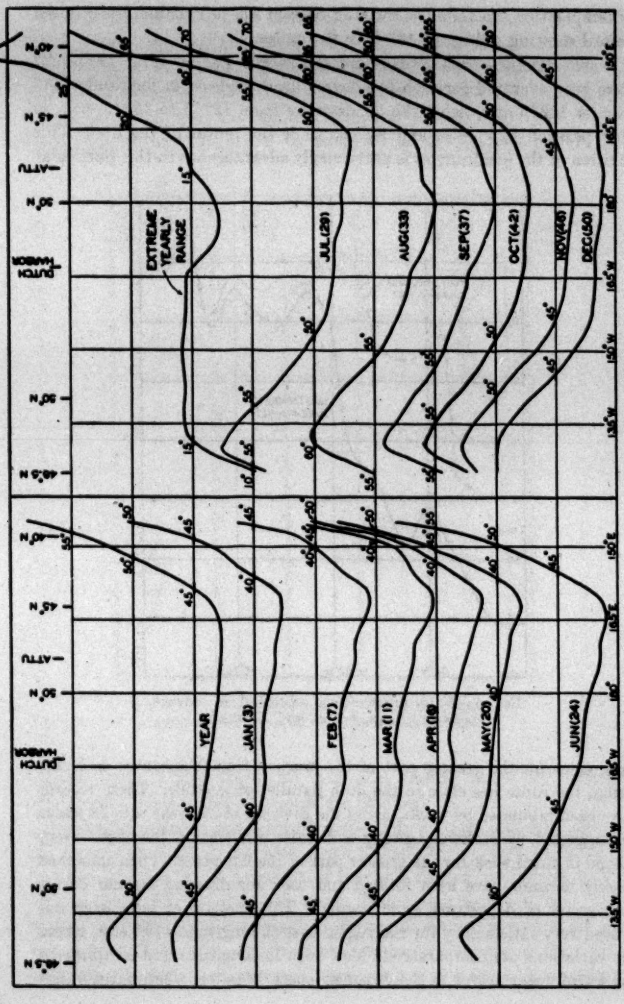

FIG. 6—Normal water-temperatures of the North Pacific, plotted against longitude.

tions are found, it would be better to use smaller areas if a special study of this region were contemplated. The results obtained in this region are further complicated by the considerable difference in the eastbound and westbound routes followed by the steamers. Nothing has as yet been done with the records taken between Yokohama and Hongkong.

Figure 6 shows the normal temperatures of the water of the North Pacific plotted against the longitude, using for this purpose the average of the results of the eastbound and westbound journeys wherever they fall in different quadrangles. The curves are plotted for the middle week of each month, for the yearly average, and for the average yearly range. The cold current off the North American coast described by McEwen [4] is

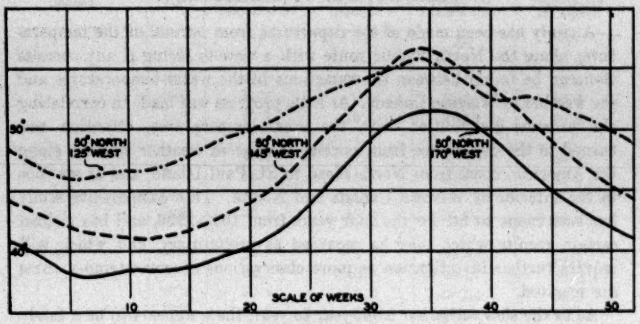

FIG. 7—Yearly water-temperature variations in three typical areas of the North Pacific.

clearly shown in summer, but not in winter. At latitude 50° north, in August its effect is felt as far as five degrees of longitude from the coast. In summer, also, the warm current off Japan is more effective than in winter, displacing the point of minimum temperature from 160° east in winter to 180° in summer, and at the same time increasing the temperature-gradient in the water on both sides of the Pacific.

Figure 7 shows the yearly variations in three typical areas. These show very distinctly a secondary maximum of temperature occurring in the water along the coast about the 43d week (end of October). A secondary minimum is also found in the coast water about the 11th week (middle of March) and a little later farther out. The secondary minimum is evidently due to the appearance of the cool seasonal current along the

[4] G. F. McEWEN, Bull. Nat. Res. Counc., no. 61: 222-235 (1927).

coast, and the 43d week maximum to the suppression of this current, allowing the warm water of the easterly current to approach the shore. McEwen considers this current as mainly caused by the prevailing winds, and it is therefore interesting to notice that the average duration of the southwesterly winds which prevail at Victoria in summer is from the 11th to the 39th weeks.

A similar secondary minimum is found in the water off the Aleutian Islands about the 15th week (middle of April). The observations of ocean currents are less complete in this region, but it seems likely that here also the effect is due to a seasonal change in the current distribution.

VARIATIONS OF TEMPERATURE

A study has been made of the departures from normal of the temperatures along the North Pacific route with a view to seeing if any correlation can be found between the variations in the water-temperatures and the weather of Western Canada. As little progress was made in correlating the pressure-distribution with the ocean-temperatures, attention was turned to the departures from normal at selected weather stations along the American coast from North Head to St. Paul Island, and at stations in the interior of Western Canada and Alaska. This comparative study has been made so far for the four years from 1923-1926, and has yielded certain results which may be regarded as preliminary, and which will require further investigation as more observations of ocean-temperatures are received.

As to the slow variation from year to year, there appears to be a fairly definite correlation, especially in winter, between the temperature-gradient in the water and the intensity of the Aleutian low, as shown by the pressure at Dutch Harbour. When the temperature-gradient is large for the time of year, the pressure at Dutch Harbour is low. This, however, does not apply to the regular seasonal changes, since in summer, when the temperature-gradient in the water has its normal maximum, the Aleutian low is inactive, so that other factors must be involved.

As has been noticed before, a failure of the Aleutian low to operate with its usual intensity over an extended period in winter results in a cold season in the Canadian West, and we find therefore a correlation between the temperature-gradient in the water and the temperature at Calgary. When the temperature-gradient is low (cool water along the coast or warm water off the Aleutian Islands) a cold winter is experienced in the Canadian West (but not necessarily in Alaska).

Table 1 shows the mean ocean-temperature (from 124° west to 172°.5 east), the mean fall of temperature over the same region, the mean

pressure at Dutch Harbour, and the mean temperature at Calgary, averaged for three-month periods. As far as this table goes, the correlation between the pressure at Dutch Harbour and the temperature-gradient is quite evident in winter and autumn, but apparently disappears to a great extent in summer.

In addition to this effect, as might be expected, the water apparently shares to a certain extent in the general variation of atmospheric conditions. A season of irregular weather on land is accompanied by a season

TABLE 1

Season	Year	Mean sea-temperature	Temperature-gradient	Pressure at Dutch Harbor	Temperature at Calgary
		°F	°F	in	°F
Winter	1923	38.9	6.8	29.74	20.0
	1924	40.9	10.2	29.56	22.5
	1925	41.2	9.4	29.55	19.0
	1926	43.1	12.1	29.13	30.5
Spring	1923	45.5	11.0	29.64	49.5
	1924	44.1	11.2	29.84	48.5
	1925	44.3	11.4	29.73	51.0
	1926	46.3	12.4	29.74	50.0
Summer	1923	52.7	13.2	29.85	59.0
	1924	52.5	10.7	29.84	59.0
	1925	53.4	10.0	29.83	56.5
	1926	55.0	9.0	29.88	54.5
Autumn	1923	46.5	10.9	29.45	34.0
	1924	46.2	8.6	29.73	26.5
	1925	48.4	10.7	29.46	31.5
	1926	49.6	9.6	29.45	28.5

of comparatively rapid and large fluctuations in the temperature of the water (for example, during the greater part of 1924). A generally warm (or cold) season over the whole of Northwestern America is accompanied by generally high temperature in the water. At the same time large warm or cold waves on land frequently appear in the water as well.

Unfortunately, it is still impossible to say which is cause and which effect, or whether both are not controlled by some other factor. During the four years under consideration, in only one instance have conditions changed with sufficient rapidity to permit of deciding which occurred first, the change in water-temperature or the change in the type of weather. The winter of 1923 was a period of very low water-temperature and low

gradient, with high pressure at Dutch Harbour and low temperature in British Columbia and Alberta. Then the water-temperature rose quite rapidly between the 10th and 13th weeks throughout the region from the American coast to the Aleutian Islands. The corresponding drop in pressure at Dutch Harbour took place between the 11th and 14th weeks, the temperature rise along the coast about the same time, and at Calgary about one week later. In this one case the change appears to have taken place in the water before it took place in the atmosphere, but before any rule can be laid down regarding this point many more observations of the ocean-temperatures will be necessary.

During the five years that these records have been obtained in the North Pacific there has been a progressive general rise in the temperature of the water, indicating the existence of a change with a period of several years, with some indication that a maximum occurred about the end of 1926. It cannot be said yet what influence this has upon the weather until accurate records are obtained covering at least a complete cycle, although there is some indication that the pressure at Dutch Harbour decreases with a general increase in the water-temperature, as well as with an increase in the temperature-gradient. The whole question is still undecided, and will have to be reexamined after a few more years of ocean-temperature records have been obtained.

Some connection between ocean-temperature and weather can also be traced in the more rapid fluctuations (with periods of one to three months). In a number of cases a period of a month or so of abnormally cold or warm water is accompanied by a similar period of low or high temperature on land. Out of eighteen such cases, in eleven the minimum (or maximum) temperature occurred on land before it occurred in the water; in seven cases, it appeared first in the water. The connection in this case must be indirect, and probably both the water- and air-temperatures are here affected by temporary changes in the prevailing winds.

A curious feature of the one-to-three-month period fluctuations in the water is that apparently no regularity obtains in the order in which they appear in different parts of the ocean. The maximum or minimum seems to be just as likely to occur off the American coast some two weeks before it is evident in the Aleutian Islands as it is to appear first in the West; so that sometimes the curves of departures from normal look as if there were a cold or warm wave spreading from east to west. At other times the fluctuations in the water occur simultaneously over the whole region, and this may be either before or after the corresponding land fluctuation in Southern Alaska.

Meteorological Office,
Toronto, Canada

SIGNIFICANCE OF WATER-TEMPERATURE MEASUREMENTS NOT MADE EXACTLY AT THE SURFACE

G. F. McEWEN

THE TIME REQUIRED FOR TEMPERATURE-DEPARTURES TO CROSS FROM THE WESTERN TO THE EASTERN SIDE OF THE PACIFIC, AND CHANGES IN DEPARTURES DURING THE CROSSING

G. F. McEWEN

The above two papers are published in the Journal of the Washington Academy of Sciences (18: 545-548, Dec. 4, 1928).

PROBLEMS RELATED TO ATMOSPHERIC CIRCULATION

THE EFFECT OF SURFACE-WINDS UPON OCEAN-DRIFT

G. W. LITTLEHALES

A CRITICAL REVIEW OF THE WORK OF THE INDIAN METEOROLOGICAL SERVICE IN MONSOON-PREDICTIONS

R. HANSON WEIGHTMAN

THE EFFECT OF OCEAN-CURRENTS ON THE CLIMATE OF CONTINENTS

ALFRED J. HENRY

The above three papers are published in the Journal of the Washington Academy of Sciences (18: 548-558, Dec. 4, 1928).

SECTION OF VOLCANOLOGY

(Washington, D. C., April 27, 1928)

PRESENT VOLCANIC ACTIVITY OVER THE EARTH

H. S. WASHINGTON

THE YEAR'S VOLCANOLOGICAL PUBLICATIONS

ARTHUR L. DAY

THE CLASSIFICATION OF THE HOT AREAS IN THE YELLOWSTONE PARK AND THE CAUSES OF THEIR DEVELOPMENT

E. T. ALLEN

THE ACID GASES CONTRIBUTED TO THE SEA DURING VOLCANIC ACTIVITY

E. G. ZIES

VOLCANO-RESEARCH IN THE UNITED STATES GEOLOGICAL SURVEY

T. A. JAGGAR

The above five papers were published in the number of the Journal of the Washington Academy of Sciences (18: 509-515, Nov. 19, 1928).

GENERAL

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STATUTES AND BY-LAWS OF THE AMERICAN GEOPHYSICAL UNION

(As amended to July 1, 1928)

PREAMBLE

The American Geophysical Union is hereby established by the National Research Council. It supersedes the "American Section of the proposed International Geophysical Union." The American Geophysical Union is the American National Committee of the International Geodetic and Geophysical Union and the Executive Committee of the American Geophysical Union is the Committee on Geophysics of the National Research Council. The American Geophysical Union is constituted as follows:

ARTICLE 1

Objects

(a) To assist in carrying out the objects of the International Geodetic and Geophysical Union, which are: To promote the study of problems concerned with the figure and physics of the Earth; to initiate and coordinate researches which depend upon international cooperation, and to provide for their scientific discussion and publication; and to facilitate special researches, such as the comparison of instruments used in different countries.

(b) To promote and coordinate the study of the various branches of geodesy and geophysics in the United States of America and its outlying territories.

ARTICLE 2

Membership

The membership of the American Geophysical Union shall be as follows:

(a) Those who composed the membership of the "American Section of the proposed International Geophysical Union" on July 1, 1919.

(b) Those who may be appointed by the Executive Board of the National Research Council upon nominations submitted by the Executive Committee of the American Geophysical Union.

(c) The Chairman of the Division of Foreign Relations, the Chairman of the Division of Physical Sciences, the Chairman of the Division of Chemistry and Chemical Technology, the Chairman of the Division of Geology and Geography, and the Chairman of the Division of Biology and Agriculture, of the National Research Council, members *ex officio*.

(d) The American officers of the International Geodetic and Geophysical Union and of its Sections, members *ex officio*.

ARTICLE 3

Sections

The American Geophysical Union shall be divided into Sections, in accordance with the organization of the International Geodetic and Geophysical Union, as follows: (a) Geodesy; (b) Seismology; (c) Meteorology; (d) Terrestrial Magnetism and Electricity; (e) Oceanography; and (f) Volcanology.

The members shall designate the Section, or Sections, to which they will belong. The *functions of the Sections*, in their respective fields, shall be the promotion of the objects of the American Geophysical Union.

ARTICLE 4

Officers of the American Geophysical Union

The *Officers of the American Geophysical Union* shall consist of a chairman and a vice-chairman, elected to serve for a period of three years, and not to be eligible for immediate re-election to their respective offices; and a general secretary, to serve for a period of three years.

ARTICLE 5

Officers of Sections

The *Officers of the Sections* of the American Geophysical Union shall consist for each Section of a chairman, a vice-chairman, and a secretary, whose eligibility and periods of office shall correspond to those of the Union. The Chairman of each Section shall have the power to appoint, with the right to vote, a representative of the Section to such meetings of the Executive Committee of the Union as he may be unable to attend.

ARTICLE 6

Executive Committee

The *Executive Committee* shall consist of the chairman, the vice-chairman, and the general secretary of the American Geophysical Union, and of one representative from each of the sections of the Union, who shall be the chairman thereof or a member appointed by him; and, in addition, *ex officio*, the American officers of the International Geodetic and Geophysical Union, and of its Sections, the chairman of each of the Standing Committees of the American Geophysical Union, and the chairman of each of the following Divisions of the National Research Council; Foreign Relations, Physical Sciences, Chemistry and Chemical Technology, Geology and Geography, and Biology and Agriculture. This Committee shall have charge of all administrative matters of the American Geophysical Union, and shall be the representative of the Union in its relations with the National Research Council and with the International Geodetic and Geophysical Union. The Executive Committee, in consultation with the Sections, shall nominate to the Executive Board of the National Research Council delegates, or representatives, to the meetings of the International Geodetic and Geophysical Union and of its Sections, in accordance with the regulations fixed by the International Research Council for the voting power of the United States of America.

ARTICLE 7

Annual Meetings

The American Geophysical Union and its Sections shall meet annually at such time and place as may be chosen by the Executive Committee of the Union. The officers of the Union and of the Sections shall be elected at this annual meeting.

ARTICLE 8

Special Meetings

Special Meetings of the American Geophysical Union, or of its Sections, may be called when necessary by the respective chairmen.

ARTICLE 9

By-Laws

The American Geophysical Union is authorized to enact such by-laws as may be necessary for the performance of its functions and duties.

ARTICLE 10

Amendments

Amendments to the Statutes of the American Geophysical Union shall be subject to the approval of the National Research Council.

BY-LAWS

The fiscal year of the American Geophysical Union shall conform to the fiscal year of the National Research Council.

Standing committees on Statutes and By-laws, on Membership, on Meetings, and on Budget, shall be appointed for the ensuing fiscal year by the Chairman-elect of the Union prior to the beginning of each year.

All committees of the American Geophysical Union shall terminate at the end of the fiscal year for which they may be appointed.

Meetings of the Union shall be called at least thirty days in advance, and those present at the meeting shall constitute a quorum.

Meetings of the Executive Committee shall be called by the Chairman, and those present shall constitute a quorum.

Final action shall not be taken by the Executive Committee on matters affecting any Section in the absence of the Chairman of such Section, or his representative.

No mail ballot shall be closed until at least thirty days after the date of issue.

After thirty days' notice has been given, amendments to the Statutes (all of which are subject to the approval of the National Research Council) may be voted on either by mail or at a regular meeting of the Union.

Amendments to the By-Laws may be proposed either by mail or at a regular meeting; when voted on by mail they require for adoption a majority vote of

the members; when voted on at a regular meeting they require for adoption a three-fourths vote of the members present.

Any amendment to the Statutes or By-Laws proposed by at least five members shall be submitted for vote to the members of the Union by the Executive Committee.

A member of the American Geophysical Union may be dropped from the Union by a three-fourths vote of the members of the Executive Committee.

Statutes and By-Laws adopted by a Section shall not conflict with the provisions of the Statutes and By-Laws of the Union.

Matters pertaining to a Section or Sections, and not pertaining to the Union as a whole, shall be acted upon by the Section or Sections concerned.

ALPHABETICAL ADDRESS LIST OF MEMBERS OF THE AMERICAN GEOPHYSICAL UNION[1]

DR. C. G. ABBOT (*c, d*)
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DR. L. J. BRIGGS (*a, e, f*)
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Harvard University
Cambridge 38, Massachusetts

PROFESSOR W. M. DAVIS (*e*)
Professor Emeritus
Harvard University
23 Hawthorn Street
Cambridge 38, Massachusetts

[1] Total number of members on July 1, 1928, is 75. The letters following each name indicate the sections with which the member is affiliated, these being (*a*) Geodesy, (*b*) Seismology, (*c*) Meteorology, (*d*) Terrestrial Magnetism and Electricity, (*e*) Oceanography, and (*f*) Volcanology.

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Coast and Geodetic Survey
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Volcano Post Office, T. H.

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Harvard University
Readville, Massachusetts

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St. Louis University
St. Louis, Missouri

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La Jolla, California

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Chicago, Illinois

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California Institute of Technology
Pasadena, California

DR. H. F. MOORE (*e*)
Linville Falls, North Carolina

[1] Died December 24, 1928.

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Chicago, Illinois

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American Museum of Natural History
New York City

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P. O. Box 131
Newark, Delaware

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New Haven, Connecticut

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127 North 19th Street
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Stanford University, California

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Stanford University, California

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Pasadena, California

DR. FRED E. WRIGHT (*a, b, f*)
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2801 Upton St. N. W.
Washington, D. C.

EX OFFICIO MEMBERS

The Chairman, Division of Foreign Relations, National Research Council.

The Chairman, Division of Physical Sciences, National Research Council.

The Chairman, Division of Chemistry and Chemical Technology, National Research Council.

The Chairman, Division of Geology and Geography, National Research Council.

The Chairman, Division of Biology and Agriculture, National Research Council.

OFFICERS OF THE UNION

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Vice-Chairman, G. W. Littlehales (1926-1929)
General Secretary, J. A. Fleming (1928-1931)

OFFICERS OF SECTIONS

Section	Chairman	Vice-Chairman	Secretary
Geodesy	William Bowie (1926-1929)	F. E. Wright (1926-1929)	W. D. Lambert (1928-1931)
Seismology	L. H. Adams (1926-1929)	N. H. Heck (1926-1929)	Frank Neumann (1928-1931)
Meteorology	H. H. Kimball (1926-1929)	G. W. Littlehales (1926-1929)	A. J. Henry (1926-1929)
Terrestrial Magnetism and Electricity	N. H. Heck (1926-1929)	J. H. Dellinger (1926-1929)	J. A. Fleming (1926-1929)
Oceanography	R. L. Faris (1928-1929)	W. J. Peters (1928-1929)	Austin H. Clark (1926-1929)
Volcanology	T. A. Jaggar, Jr. (1926-1929)	F. E. Wright (1926-1929)	C. N. Fenner (1928-1929)

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MEMBERSHIP OF SECTIONS[1]

Section (a) Geodesy (number of members, 24)

[1] The affiliations with sections of the ex officio members are not shown in these lists, owing to inevitable changes from year to year.

Louis A. Bauer
William Bowie, Chairman (1926-1929)
L. J. Briggs
E. W. Brown
R. L. Faris
George E. Hale
D. L. Hazard
L. M. Hoskins
Lewis V. Judson
W. D. Lambert, Secretary (1925-1928)
A. O. Leuschner
G. W. Littlehales
J. B. Macelwane
A. A. Michelson
F. R. Moulton
Frank Neumann
H. F. Reid
Frank Schlesinger
W. F. G. Swann
S. D. Townley
C. E. Van Orstrand
H. S. Washington
H. O. Wood
F. E. Wright, Vice-Chairman (1926-1929)

Section (b) Seismology (number of members, 35)

L. H. Adams, Chairman (1926-1929)
J. A. Anderson
Louis A. Bauer
N. L. Bowen
William Bowie
E. W. Brown
R. A. Daly
A. L. Day
R. L. Faris
C. N. Fenner
J. A. Fleming

SECTION (b) SEISMOLOGY—*Continued*

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L. M. Hoskins
W. J. Humphreys
T. A. Jaggar, Jr.
Lewis V. Judson
W. D. Lambert
A. C. Lawson
A. O. Leuschner
A. G. McAdie
J. B. Macelwane
C. F. Marvin
A. A. Michelson
Frank Neumann
H. F. Reid
G. T. Rude
Francis A. Tondorf
S. D. Townley
C. E. Van Orstrand
T. Wayland Vaughan
H. S. Washington
Bailey Willis
H. O. Wood
F. E. Wright

SECTION (c) METEOROLOGY (number of members, 27)

C. G. Abbot
J. P. Ault
W. D. Bancroft
Louis A. Bauer
W. R. Blair
E. H. Bowie
H. H. Clayton
J. A. Fleming
O. H. Gish
W. R. Gregg
George E. Hale
A. J. Henry, Secretary (1926-1929)
W. J. Humphreys
H. H. Kimball, Chairman (1926-1929)
G. W. Littlehales, Vice-Chairman (1926-1929)
A. G. McAdie
J. B. Macelwane
C. F. Marvin
S. J. Mauchly
R. A. Millikan
F. R. Moulton
G. P. Paine
W. E. Parker
G. T. Rude
W. F. G. Swann
R. DeC. Ward
Bailey Willis

SECTION (d) TERRESTRIAL MAGNETISM AND ELECTRICITY (number of members, 26)

C. G. Abbot
J. P. Ault
L. W. Austin
S. J. Barnett
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W. R. Blair
J. H. Dellinger, Vice-Chairman (1926-1929)
R. L. Faris
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G. W. Littlehales
A. G. McAdie
J. B. Macelwane
C. F. Marvin
J. A. Fleming, Secretary (1926-1929)
O. H. Gish
W. R. Gregg
George E. Hale
D. L. Hazard
N. H. Heck, Chairman (1926-1929)
A. J. Henry
S. J. Mauchly
R. A. Millikan
Frank Neumann
W. E. Parker
W. J. Peters
W. F. G. Swann

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William Bowie
L. J. Briggs
A. H. Clark, Secretary (1926-1929)
F. W. Clarke
R. A. Daly
W. M. Davis
R. L. Faris
J. A. Fleming
Harvey C. Hayes
N. H. Heck
A. J. Henry
W. D. Lambert
G. W. Littlehales
A. G. McAdie
G. F. McEwen
H. A. Marmer
S. J. Mauchly
A. A. Michelson
H. F. Moore
F. R. Moulton
Robert C. Murphy
W. E. Parker
W. J. Peters
H. F. Reid
G. T. Rude, Vice-Chairman (1926-1929)
C. E. Van Orstrand
T. Wayland Vaughan, Chairman (1926-1929)
Roger C. Wells
Bailey Willis

SECTION (f) VOLCANOLOGY (number of members, 26)

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E. T. Allen
N. L. Bowen
William Bowie
L. J. Briggs
E. W. Brown
F. W. Clarke
Whitman Cross
R. A. Daly
A. L. Day
C. N. Fenner
W. J. Humphreys
T. A. Jaggar, Jr., Chairman (1926-1929)
J. B. Macelwane
C. F. Marvin
S. J. Mauchly
F. A. Perret
H. F. Reid
R. B. Sosman, Secretary (1925-1928)
George Steiger
C. E. Van Orstrand
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William Bowie, 1920-22	Louis A. Bauer, 1920-22	H. O. Wood, 1919-21
Louis A. Bauer, 1922-24	Arthur L. Day, 1922-24	W. J. Humphreys, 1921-22
H. F. Reid, 1924-26	H. S. Washington, 1924-26	William Bowie, 1922-25
H. S. Washington, 1926-29	*G. W. Littlehales, 1926-29*	*J. A. Fleming, 1925-31*

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SECTION	CHAIRMAN	VICE-CHAIRMAN	SECRETARY
(a) Geodesy	William Bowie, 1920-22	J. F. Hayford, 1920-22	H. O. Wood, 1920-22
	J. F. Hayford, 1922-24	R. L. Faris, 1922-24	William Bowie, 1922-25
	R. L. Faris, 1924-26	J. F. Hayford, 1924-25	*W. D. Lambert, 1925-31*
	William Bowie, 1926-29	William Bowie, 1925-26	
		F. E. Wright, 1926-29	
(b) Seismology	H. F. Reid, 1920-22	J. C. Branner, 1920-22	H. O. Wood, 1920-22
	W. J. Humphreys, 1922-24	J. B. Woodworth, 1922-24	D. L. Hazard, 1922-28
	J. B. Woodworth, 1924-26	L. H. Adams, 1924-26	*Frank Neumann, 1928-31*
	L. H. Adams, 1926-29	*N. H. Heck, 1926-29*	
(c) Meteorology	C. F. Marvin, 1920-22	W. J. Humphreys, 1920-22	*A. J. Henry, 1920-29*
	E. H. Bowie, 1922-24	R. DeC. Ward, 1922-24	
	C. G. Abbot, 1924-26	H. H. Kimball, 1924-26	
	H. H. Kimball, 1926-29	*G. W. Littlehales, 1926-29*	
(d) Terrestrial Magnetism and Electricity	Louis A. Bauer, 1920-22	W. F. G. Swann, 1920-22	*J. A. Fleming, 1920-29*
	W. F. G. Swann, 1922-24	Louis A. Bauer, 1922-24	
	Louis A. Bauer, 1924-26	N. H. Heck, 1924-26	
	N. H. Heck, 1926-29	*J. H. Dellinger, 1926-29*	
(e) Oceanography	G. W. Littlehales, 1920-22	A. G. Mayor, 1920-22	J. T. Watkins, 1920
	J. P. Ault, 1922-24	G. W. Littlehales, 1922-24	W. E. Parker, 1920-23
	N. H. Heck, 1924-26	W. J. Peters, 1924-26	G. T. Rude, 1923-26
	T. W. Vaughan, 1926-28	*G. T. Rude, 1926-28*	*A. H. Clark, 1926-29*
	R. L. Faris,[2] 1928-29	W. J. Peters,[2] 1928-29	
(f) Volcanology	H. S. Washington, 1920-22	R. A. Daly, 1920-22	H. O. Wood, 1920-21
	L. H. Adams, 1922-24	T. A. Jaggar, Jr., 1922-24	R. B. Sosman, 1921-28
	T. A. Jaggar, Jr., 1924-29	N. L. Bowen, 1924-26	*C. N. Fenner, 1928-29*
		F. E. Wright, 1926-29	
(g) Geophysical Chemistry[3]	Arthur L. Day, 1920-22	F. W. Clarke, 1920-22	R. B. Sosman, 1920-24
	H. S. Washington, 1922-24	Whitman Cross, 1922-24	

DATES OF ANNUAL MEETINGS OF UNION AND OF ITS SECTIONS

First, April 23, 1920	Fourth, April 17-19, 1923	Seventh, April 29, 30, 1926
Second, April 18-20, 1921	Fifth, May 1-3, 1924	Eighth, April 28, 29, 1927
Third, March 6, 8, 1922	Sixth, April 30, May 1, 1925	Ninth, April 26, 27, 1928

DECEASED MEMBERS

J. C. Branner, died March 1, 1922
A. G. Mayor, died June 24, 1922
R. S. Woodward, died June 29, 1924
J. F. Hayford, died March 10, 1925
J. B. Woodworth, died August 5, 1925
S. J. Mauchly, died December 24, 1928

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[1] The names of the officers for the ninth annual meeting are indicated by italics.
[2] Elected at the ninth annual meeting to complete terms of officers who resigned because of expected absences from the United States during 1929.
[3] Discontinued May 31, 1924, as International Union failed to provide for such a Section.